The Lower Damodar River, India

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The Lower Damodar River, India

Understanding the Human Role in Changing Fluvial Environment

by

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Springer

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This book is dedicated to the memory of my late Parents
Shri Mohini Mohan Bhattacharyya
Smt Jyotirmoyee Bhattacharyya

Foreword 1

This is a time when the global impacts of human society are pushing governments around the world to actively search for new strategies to protect their social and economic assets from the threat of rapid climate change and its ecological and geomorphic consequences. Nowhere is this more apparent than in South and East Asia. China has recently engaged in the largest river impoundment project in this planet's history. In 2007 the Supreme Court of India orders the national government to proceed with planning for an engineering feat of unprecedented scope and scale: the hydrologic interlinking of all of the subcontinents major river basins for the purpose of equitable distribution and use of monsoon rains. In 2009 South Korea began its Four Major Rivers Restoration project. Already well underway, the government is committed to spending over $14 billion dollars in a little as 3 years to massively alter channel storage and conveyance capacities; ostensibly in response to anticipated water shortages to come. Rivers and coastlines, because they are the most obvious interfacing between the hydrosphere and our continental homes, are the front lines along which much of drama of human adaptation to climate change will play out.

It is appropriate then, that we find ways now to step back, and carefully review our experiences and history with regard to that age-old dance between humans and rivers, a relationship that spawned the earliest civilizations of man. A relationship where man often masters river, but not infrequently river masters man. K. Bhattacharyya's study of the Damodar River provides us with just this opportunity. Set in a lower tributary of the mighty Ganga (Ganges) this is a story of human ecology, river geomorphology, and hydrologic engineering. Adaptation by both the riparian communities and the river itself to a trajectory of mutually induced change make it also a fascinating ecological study in the truest sense of the word. In this drama of riparian ecology man is not a bystander nor a reference point for determining "ecosystem values", but an actor and participant. The authors attention to fine detail in the data, and also to the history of geographic and geomorphic concepts required to provide perspective make this a scholarly work of great value. Her personal connections with the riparian community, and with the academic and engineering community as well provide valuable insight into the human aspects of this story; this contributes to a certain compelling sense of drama that emerges from this study. I understand entirely M.G. Wolman's and others push to have Kumkum publish her work in book form. It is a recounting of a particular history, relevant to our current and future negotiation with nature, which is both compelling and informative.

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March 20, 2010

Foreword 2

Industrialization, urbanization, economic development, and rapid population growth have necessitated deliberate human interference with most rivers from all the major basins in the world in order to exploit their water and control their courses. The Damodar River is no exception to this. Although such interference in this relatively small river valley started more than three centuries ago, it intensified after the independence of India from Britain in 1947. Since then, the water of the Damodar River has been used to irrigate farm lands during the dry season, for hydro-power development, as well as for navigation, fisheries, and industrial development. Many flood control structures have also been put in place to reduce the impacts of destructive floods. These and other changes made to control river flow and to use its water have benefited residents of this river valley, but not without social and environmental cost. Valley residents have struggled to adapt to these changes and maximize their limited resources while the river ecology has suffered over the decades.

I was born and brought up in Bangladesh, a country criss-crossed by rivers, most of which are either tributaries or distributaries to three great rivers of the world: the Ganga, the Brahmaputra, and the Meghna (GBM). These three rivers form the GBM basin, one of the largest trans-boundary river basins in the world. With a total catchment area of the 1.74 million km^2, this densely populated basin contains one of the richest agricultural areas in the world and its rivers are intricately linked with the very survival of millions of people. Rivers supply much needed irrigation water for crop cultivation and serve as arteries of commercial transportation. Since the GBM basin receives heavy annual rainfall and approximately 85% of that rain occurs in the summer, rivers of this basin, carry a large discharge and a heavy sediment load. This causes these rivers to be extremely unstable, with channels that are literally, constantly migrating. As a result, the GBM basin experiences annual flooding, which adds fresh silt to crop fields making the land very fertile. While most floods rejuvenate land and lives, some bring misery and death.

The Damodar River is contained within this basin. All school-going children in West Bengal and Bangladesh have heard stories about the mighty Damodar and how Ishwar Chandra Vidyasagar – a great scholar, philosopher, educator, and reformer of Bengal during the colonial period – swam across this river in a storm in order to obey a summons from his mother. Later, as a graduate student of geography, I learned about the pioneering endeavor of the Indian government, the Damodar Valley Corporation (DVC). While my interest in the Damodar River is personal, what has happened and what is happening now in terms of exploiting the water resource of the Damodar is no different from any other river in the GBM basin, or for that matter, any other populated major basin of the world.

Therefore, irrespective of geographic area, this book will be of tremendous value to scholars, researchers, teachers, students, and others interested in how public policies change river morphology and how such change affects both the physical and human environment.

This excellent book is based on Dr. Bhattacharyya's Ph.D. dissertation, which she completed from The University of Burdwan under the expert supervision of Manjusri Basu, Reader in Geography of the same University. Her Ph.D. committee members included prominent and famous personalities like M. Gordon (Reds) Wolman, B. Howard Griswold Professor of Geography and International Affairs, Johns Hopkins University, USA and Monotosh Bandyopadhyay, Professor of Geography, University of Calcutta. Since she completed her dissertation, Dr. Bhattacharyya updated all information. She spent a tremendous amount of time collecting relevant information through intensive field work and in doing so she followed rigorous scientific procedures. Other sources have been utilized to gather pertinent information. Her depth and knowledge about the subject matter of this book are reflected in her holistic and thorough interpretation of the field data. It presents well-documented research findings in an engaging style. Dr. Kumkum Bhattacharyya is new to academia in North America, but she has a very high potential to become one of the top in her field of research in the near future.

In writing this book, Dr. Bhattacharyya uses a broad perspective, which makes this book interesting not only to physical and human geographers, but also to scholars from other related disciplines interested in the environmental dynamics of rivers in general and the Damodar River in particular. I am honored to write a foreword for this insightful, valuable, and useful book which will advance our knowledge and understanding of how humans have interacted and interfered with rivers to their benefit. I congratulate Dr. Kumkum Bhattacharyya for presenting us with this outstanding book, and I invite all of you to read it.

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Foreword 3

Kumkum Bhattacharya's Book has a novel approach. Ecological considerations have been emphasized starting from the completion of the Damodar River Valley Project and also during his partial completion. Emphasis by the scholars was given to study the economic consequences with significant reference to displacement of famers caused by the constructions of canals and reservoirs. Geographers then contributed to the research of socio-economic advantages of the Damodar Valley research. Two Geography departments belonging to the states of West Bengal and Bihar – Calcutta University and Patna University – contributed to a specialized research funded by the government studying the socio-economic effects of the Damodar River Valley (DVC) project. Professor Kanangopal Bagchi who headed the Calcutta University, Department of Geography, based research team concluded in one of his papers:

> The DVC developments will improve the economic situation by creating infrastructures; in fact, rural electrification, construction of hard surfaced roads, and sinking of tube-wells, have already started although the pace has not been up to expectations so far. Even within this limited growth, villages and urban centers are progressing, striving to promote measures which fight drought, which is more or less endemic within the upper catchment, and floods, which are chronic in the delta. (K. Bagchi "The Damodar Valley Development and Its Impact on the Region", In Allen G. Noble and Ashok K. Dutt Editors: *Indian Urbanization and Planning: Vehicle of Modernization*, 1977, New Delhi, Tata McGraw-Hill Publishing Company Limited: pp. 232–241).

Bhattacharya book considers ecological and human repercussions of the project. It aptly recommends "better human and environment interactions". The construction of dams and reservoirs changes the natural flow of the rivers with ecological consequences. This book suggests a change of strategy to suit the interest of the people. The book also recognizes that in Bihar the project generates electricity that supplies vast area helping industrialization, city lighting and pump irrigation while in West Bengal (Lower Damodar Region), the effect of the project is primarily to control in floods and provide irrigation through canals. The ecological alterations are felt more in the lower Damodar region because here floods have been controlled and river water has been redirected-both changing the local ecology. One additional aspect needs to be considered, the aspect of climate change which is likely to cause excessive rainfall or drought occasionally. One encouraging aspect of such change is that the Damodar Valley area is not affected by excessive floods caused by melting of Himalayan and Tibetan snow.

The book is based on extensive research and field work, it is written well. It is based on conceptualization of different ideas and has strong theoretical basis; making a sound scholarly contribution. It is highly recommended for libraries all over the world. It also makes an excellent reading for those interested in developing country river geography and consequences of dam and reservoir construction.

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Preface

Since ancient times, river floods and control structures have been the basis for riverine civilizations of riparian landscapes. One can argue that civilization as we know it would not have arisen without river control. Even now, dams continue to act as bulwarks against catastrophic flood destruction all over the world. River water utilization and river control structures have formed the mainstay of planning policy in decolonized developing countries in the tropics in their quest for self-reliance since the early nineteen forties. Despite these enormous benefits, however, river control has sometimes had disastrous social and environmental consequences. Not surprisingly, the large-scale ecological damage and human suffering associated with river control has been particularly significant in the developing countries where dams have provided maximum benefit.

I was born and brought up in the Ganga Valley of Lower Bengal. The River Ganga was a constant companion in my childhood. When I grew up, the river became a source of inspiration for me. This proximal relation with the river was the true initiator for the creation of this book. I started dreaming of working with the river. I decided to pursue an academic career focusing my interest on understanding the riverine regime and its paradoxes. As a graduate student of Geography, I had been privileged to visit and study the Ganga (Hooghly-Bhagirathi), Damodar, Ajay, Kaliaghai, Kasai and Kangsabati Rivers. With a keen interest I observed everywhere how indigenous technological innovations helped better water resource management and how flooding was accepted by the riparian communities as a positive factor. The disadvantage of floods in one season was converted into an advantage in another.

I was inspired by Manjusri Basu, Reader in Geography of The University of Burdwan. She was instrumental in sparking my interest in the way people interacted with their fluvial environment and responded as a community at both micro and macro levels. This subject haunted me for years and drove me to many places in search of answers. By the beginning of 1990, I was granted a University scholarship and approved for the doctoral program at the same university under the supervision of M. Basu. I selected the Lower Damodar River, a subsystem of the Ganga River as my area of focus. One reason for this choice was the fact that floods have concerned humanity from the dawn of civilization to the present era and this part of the Damodar is notorious for causing flood havoc despite control measures. Also, the Lower Damodar has a flood history dating back to 1665 and is one of the innumerable South Bengal Rivers chained by embankments, the first control measures, predating the British Period. Besides, the Damodar was the first river selected in independent India for a multipurpose river valley development project known as the Damodar Valley Corporation (DVC), a body modeled on the Tennessee Valley Authority (TVA) of the United States. Beginning with the construction of embankments in the eighteenth century and subsequent addition of weirs, barrage and dams, the Lower Damodar River has been transformed into a reserved controlled channel with significant post-dam reduction in regular flow and in monsoon discharge but with the increase of non-monsoon flow with very high variability. The alluvial bars locally known as *Char* or *Mana* that have emerged on the riverbed due to decreased flow are now used as a resource base mostly by Bangladeshi refugees who have matched land use at fine scales to flood experiences applying a concept of flood zoning to the riverbed and effectively assessing short-term risks and long-term benefits. According to M. Basu, "Colonization on the riverbed with semi-permanent alluvial sandbars was actually due to the chance discovery of the fertility of the water-bound landmass". We were fascinated by the complex, sophisticated interrelationships between the riverbed settlers and the natural environment in the presence of floods and dams. As a field researcher, I lived on the sandbars of the Damodar River in order to observe and interview people living in that flood-prone environment. During that time I also collected information on floods, water resources, human perception, adaptation, flood plain zoning, and other topics.

I have since had the opportunity to present the results of my research at different national and international seminars in India and abroad. I also had the opportunity to present papers on the impacts of dams and human perception and adjustment in riverbed sand bars at the Conferences of *International Association of Geomorphologists* held in Singapore in 1995 and in Bologna of Italy in 1997. My presentation in Singapore concluded with a question: should we save our rivers or save the communities? "This is very interesting and fascinating work" – this was the immediate response of M. Gordon (Reds) Wolman one of the most gentle and amiable personalities I have ever encountered. He was genuinely excited and curious about my research. Since 1995 I have been nurtured by his vast encyclopedia of ideas. While writing this preface, I came to know that Prof. Reds Wolman is no more. I have lost a true mentor who was always generous with his time and provided continuous guidance for this book which is based on my PhD dissertation that he examined.

The University of California, Berkeley awarded me a post-doctoral research fellowship in 2002 along with the opportunity to work on the impacts of dams and reservoir sedimentation under the supervision of Matt Kondolf. I had numerous opportunities to visit and study the rivers and reservoirs in California on weekend field trips to further develop my research on the Damodar River where significant silting in the Maithon and Panchet reservoirs and the resulting decrease in flow in the main channel has led to the creation of a series of settled sandbars. This has resulted further in deforestation and anthropogenic degradation of the river itself. Refugees have inhabitated the sandbars despite adverse environmental conditions.

In defiance of economic, social and political limitations, they have persevered in adjusting to the inhospitable surroundings. This hydraulic society poses a challenge to technology as well as to the government in the quest to confront and control flood hazard.

Human impact on the riverine system and the socioeconomic environment has become a matter of great concern in the contemporary world. Geographers, ecologists, planners, engineers and scientists all over the world are paying close attention to the relationship between humans and the environment. M. Gordon (Reds) Wolman, commenting on riverbed settlers in the Damodar River, wrote (personal communication dated April 10, 1996) "is there a set of design flow releases that will at least reduce frequent flooding? Of course, the rare largest floods may be the ones causing the most severe damage to people and property. That may require preventing settlement on the island, a difficult thing to do". We would hesitate to ask river communities to abandon sandbars that have been under cultivation for decades but we would like to propose that agriculture or human interferences be abandoned with the active channel. Our communities must be saved but not at the cost of continuous deterioration of our river ecosystem. The aim should be to optimize the present human uses and to preserve the river as a living system not only for its inherent ecological value but to satisfy future human needs on a sustainable basis. Surely both the river as well as the communities can be saved in this way?

There is a lot of active ongoing research on global climate change. The drastic modification of our river systems has received far less attention. This research attempts to redress the balance by assessing a controlled river in its pre-dam and post-dam periods, reviewing the positive and negative impacts of control structures, reviewing the socio-economic significance of such control measures and human perception and adaptability within the riverbed, and identifying policy options to minimize the negative effects while maximizing the positive ones. This case study of a flood-prone Indian river can be used as a model for planning and managing this and other rivers of similar nature in India and elsewhere. This study may also be used as a good example of how the harnessing of a river and excessive human interference with natural systems alters its fluvial regime. Further, this research would provide an in-depth case study of floods and modification of the hydrological cycle due to human interference, and human adjustment with floods and dams. Therefore, the outcome of the study may be used as a knowledge base for students, researchers, river experts and planners of river valley projects. "We should promote scientific analysis of human impacts on river system and collaborative science-based approaches to river conservation and management. Collaboration is central to ecosystem management," Mike J. Wiley, Roosevelt Professor of Ecosystem Management from the University of Michigan, Ann Arbor, said. He added "I have always found that people really do care and want to manage their water resources more effectively. The difficult part is developing effective lines of communication".

As a researcher, I have assembled extensive data from multiple sources over a period of time and presented it without bias so that this information may be used to make more intelligent decisions in assessing the balance between the benefits and unfavorable downstream effects of dams. Admittedly, the work of a single researcher cannot provide the more complete impact analysis that would be possible through an inter-disciplinary approach taken by a team. Nevertheless, an attempt has been made in this book to focus on that effort by presenting a thorough, data-driven review and analysis of the human-made downstream environment of a controlled tropical river, the Damodar, from an applied geomorphological perspective within a wider geographical framework. The book addresses a topic that is gaining in importance and will remain relevant in the forseeable future. I hope it will make a valuable contribution to research on human environment interactions.

Acknowledgments

This book contains the results of 7-year PhD research project conducted by me under the proficient supervision of Manjusri Basu (Ex-Reader), Department of Geography, The University of Burdwan, India. I hereby express my heartiest sense of gratitude to Ms. M Basu for proving direction, continuous constructive criticism, encouragement and editorial assistance during my research period. This time-bound research project has been funded by The University of Burdwan and due to personal interest the research was carried on, based upon field surveys, over extensive areas for a long period. The author thanks The University of Burdwan and University of California, Berkeley, CA for their financial support for this research. I am grateful to PK Sen (Late Professor, Department of Geography, The University of Burdwan), Late Professor A Biswas, Dr. VC Jha (Department of Geography, Vishva Bharati University), for their valuable suggestions. I would like to thank Mr. D Bandyopadhyay, the then Minister for Agriculture, Government of West Bengal for permitting me to get access of rare and valuable data and Government documents.

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(MRO) office, DVC, Maithon), D Chowdrury (Senior Divisional Engineer, DVC, Hazaribagh), and S Vaddey (Hydraulic Engineer, US Army Corps of Engineers, Portland, OR). I am thankful to them for their valuable ideas.

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Ann Arbor, MI
Kumkum Bhattacharyya

Conversion Factors

This book uses metric units of measure. The table below is provided for those who require English units.

To convert from English unit	To metric unit	Multiply English unit by	To convert to English from metric multiply metric unit by
inches (in)	millimeters (mm)	25.4	0.03937
inches (in)	centimeters (cm)	2.54	0.3937
feet (ft)	meters (m)	0.3048	3.2808
yards (yd)	meters (m)	0.9144	1.094
miles (mi)	kilometers (km)	1.6093	0.62139
square feet (ft^2)	square meters (m^2)	0.092903	10.764
square miles (mi^2)	square kilometers (km^2)	2.59	0.3861
cubic feet (ft^3)	cubic meters (m^3)	0.028317	35.315
cubic yards (yd^3)	cubic meters (m^3)	0.76455	1.308
cubic feet per second (ft^3/s)	cubic meters per second (m^3/s)	0.028317	35.315
feet per second (ft/s)	meters per second (m/s)	0.3048	3.2808
feet (ft)	meters (m)	0.3048	3.2808
degree Fahrenheit (°F)	degree Celsius (°C)	(°F–32)/1.8	(1.8 × °C) + 32

Abbreviations

BLRO	Block Level and Revenue Office
CBIP	Central Broad of Irrigation and Power
CPCB	Central Pollution Control Board
cumec, m^3/s	Cubic meter per second
CWC	Central Water Commission
DVC	Damodar Valley Corporation
EL	Elevation
GSI	Geological Survey, India
ha	Hectare
ICAR	Indian Council of Agricultural Research
ICOLD	International Commission on Large Dams
IRS	Indian Remote Sensing
I&W Dept	Irrigation and Waterways Department
km, Km^2	Kilometer, sq kilometer
m	Meter
M.cu.m	Million cubic meters
mm	Millimeter
MRO	Manager Reservoir Operation
N.A.	Not Available
NATMO	National Atlas and Thematic Mapping Organization
NRSA	National Remote Sensing Agency
RBO	River Basin Organization
RR&RD	Refugee Relief & Rehabilitation Department
SOI	Survey of India
TVA	Tennessee Valley Authority
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations International Children's Emergency Fund
WB	West Bengal
WCD	World Commission on Dams

Contents

Chapter 1
Purpose and Perspectives

Abstract Floods, once the basis for hydraulic civilizations, are now seen mostly as sources of hazard due to negative interaction between human systems and environmental conditions at particular historical junctures within specific economic and social conditions. The same phenomenon acquires a different dimension if seen rationally as an event with both possibilities as well as perils that one can plan for and guard against. In this study on the Damodar River, physical and human environmental research has been integrated, focusing on river morphology and ecology, human use of river and sandbars or *char* lands as a resource, and policies that shape a river. This leads us to a more holistic understanding of how the forms and ecological status of a river are shaped by the interplay of environmental and anthropological processes. In other words, this research reviews the impacts of control structures in the downstream environment and also provides a detailed study of human role in changing fluvial regime through descriptions of the way in which people, ranging from refugees to local settlers, driven by diverse cultural, economic, religious, and political forces, have transformed the fluvial landscape.

Keywords Anthropogenic · Char/Mana · Control structures · Floods · Fluvial landscape · Human-environmental research · Hazard · Hydraulic civilization · Resource

1.1 Purpose

Floods and control structures, once the basis for riverine civilizations of riparian landscapes, have, despite their enormous benefits, sometimes had disastrous social and environmental consequences at particular historical junctures. Are these consequences unavoidable or is it possible to achieve a judicious balance between the various forces at play so that the benefits of river control can be realized without large-scale ecological damage and human suffering? The answer can only be found in an unbiased and extensive review of data obtained from controlled rivers over a period of time through scientific measurements and intensive field surveys. Though no single study can fill such a need, this research aims at contributing to that effort by

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presenting a thorough, data-driven review and analysis of the human-made downstream environment of a controlled tropical river, the Damodar, from an applied geomorphological perspective within a wider geographical framework. Before getting down to the nitty-gritty details and spelling out the specific objectives of this research, I would like to elaborate a little on the broader purpose and framework of the endeavor. In this context, the following sections provide a brief overview of contemporary and historical water resource management efforts and the environmental, social and economic impact they have had in different parts of the world with particular reference to South Asia.

Major ancient civilizations are hydraulic civilizations and many river basins, even those without optimum combinations of atmospheric, hydrologic and geomorphic inputs, were the sites of these civilizations. These rivers were perennial but flood-prone with fluctuating river regimes. The ancient riparian communities, therefore, were forced to take flood disaster reduction measures on the one hand and implement flood management programs on the other so as to transfer excess floodwater from surplus areas to deficit areas and from surplus seasons to deficit seasons. Artificial levees, canals, dams and many other such artifacts associated with these civilizations were nothing but river control structures and these structures were components of the geomorphic landscape from the dawn of these ancient civilizations (Bhattacharyya 1998).

The first three major civilizations that thrived about 5,000 years ago were those of the Harappans in the Indo-Gangetic Plain, the Egyptians in the Nile Valley, and the Sumerians in Mesopotamia (Easton 1964; Biswas 1970). The Indus Valley Civilization was the largest of the three most ancient civilizations and was in existence between 3000 and 1500 BC (Agarwal and Narain 1997). The Nilotic or the Egyptian civilization prospered in the Lower Nile basin between 3000 and 1750 BC and ended in a catastrophic flood of the River Nile due to tectonic upheavals (Dales 1966). The Mesopotamian civilization flourished in the Tigris-Euphrates basin in Southwest Asia and was in existence between 4000 and 600 BC. The Chinese civilization developed on the banks of the River Hwang Ho in northern China but their contribution to hydrology, especially prior to 600 BC, is not so significant (Biswas 1970). A degree of rudimentary civilization, with some of the social skills and discipline the word entails, was represented by open villages not later than the fifth millennium in the foot-hills of northern Iraq, by Catal Huyuk near Konya in southern Turkey in 7000 BC and by agricultural settlements at Mehrgarh (also about 7000 BC) on the Bolan River in the Indian sub-continent (Mishra 1995). Another recorded practice of irrigated agriculture has been traced to Jericho in the arid Jordan Valley around 7000 BC (Hirsch 1959; Wheeler 1966; Saha 1981). It is the Mesopotamian civilization that flourished in the latter half of the fourth millennium (Wheeler 1966), however, that reached the level of sophistication needed to claim the distinction of being the first real civilization.

Development of the water management systems that allowed these ancient civilizations to flourish necessitated observation of flood behavior, type and nature of silt accretion and collection and maintenance of hydro-geomorphic data for rational use of river water. In Egypt, hydrologic data near Cairo dates back to 622 AD

(Mookerjee 1989), and basin irrigation, which was first introduced in Egypt some 6,000 years ago (Willcocks 1930), is still socio-economically relevant in many tropical countries. In Egypt, the Nile floods served as the basis of successful agricultural irrigation for more than 5,000 years. People have successfully harnessed the river and become accustomed to the natural flood regime. The most important date in the Egyptian calendar was the one on which the annual inundation took place (Ward 1978). An intricate system of basin irrigation involving longitudinal dykes parallel to the main channel of the Nile to regulate flood water, a network of cross dykes and canals to control the flood water into pre-assigned basins, and a diversion channel to the naturally formed Faiyum depression for creating a storage reservoir for excess flood water for later use was developed as early as 3400 BC (Hamdan 1961; Saha 1981). It is also recorded (Payne 1959; Biswas 1970) on the authority of Herodotus that, during the Middle Kingdom (2160–1788 BC), artificial lakes were used to store water and control the high floods of the Nile.

Some scholars believe that the oldest dam was constructed in the desert land of Jawa (Jordan) around 3000 BC. Others believe that dam building began on the Nile. Near Memphis, there are relics of a masonry wall built across the river by King Menes in 4000 BC. The Romans built dams for water storage so well that some of the structures in Jordan are still in working condition today (Reifenberg 1955; Pereira 1973). Though probable, there is little known proof to show that the science of dam construction appeared in a particular place and from there it was taken to others (Agarwal and Narain 1997). About 28.8 km south of Cairo, Egypt in Wadi-el-Garawi, the ruins of Sadd-el-Kafara dam, which was built sometimes between 2950 BC and 2750 BC, are still to be observed (Biswas 1970; Ward 1978; Costa 1988). The Egyptian engineers built another dam in Syria between 1319 and 1304 BC when the first dam failed to serve its purpose. The Egyptians made great advances in water resource development during the Middle Kingdom (2160–1788 BC). Artificial lakes were built to divert high flood flows of the Nile into the historic lake Moeris through canals (Payne 1959). When the inundation came to an end, the stored water of the lake was returned to the Nile and the storage capacity of the lake was made available for the next flood period (Biswas 1967).

The Mesopotamian contemporaries of the Egyptians could not develop a similar system based on one annual inundation whose benefits could be reaped through the growing season. They were obliged to develop perennial irrigation (Brittain 1958). They reclaimed as well as irrigated land long before 3000 BC in marshes in the lowlands near the gulf and along the Lower Euphrates. Traces of these lands can still be seen from airplanes (Sarton 1952). They devised a sophisticated canal system for the twin purposes of irrigation and navigation. The canals built were very often wide enough to reduce bank erosion from rushing water from the off take points of the canals. Silt banks which were created by cleaning canals are now major topographic features (Leopold et al. 1964). The canal banks, therefore, became sites for industrial and commercial centers. Multiple uses of canals were thus one of the characteristics of the agrarian civilization of Mesopotamia (Willcocks 1930).

In the Middle East, where evapotranspiration is a severe problem and channels are lost in sand deposits, a very special system of irrigation referred to as “Quanat” or “Kanat” was developed. In this system, an artificial underground channel or a canal is used to carry water over long distances, either from a spring or from water bearing strata. This system indicates that, faced with water scarcity, the people developed knowledge about water resource engineering (Biswas 1970). The Quanat may be a Persian creation but this human-made underground river is the sole source of water for millions in Iran, the Middle East as well as in Central Asia.

The Indus Valley Civilization (3000–1500 BC) which came to light with the excavation of Harappa and Mohenjodaro in the early 1920s by Rakhaldas Bandyopadhyay, an Indian Historian, covered a vast area, more than seven times the extent of Sumer in Mesopotamia (Easton 1964). The Indus Valley and Mesopotamian civilizations were connected by close trade relations and strongly influenced each other (Garbrecht 1985; Agarwal and Narain 1997). The story of the rise and fall of the Indus valley civilization in a semiarid bio-climatic environment is the story of humans’ struggle to conquer nature and build an integrated coherent society. In this struggle for existence, the Harappans’ response to the challenge of nature, which mainly came from the River Indus, was a positive one. They adopted measures to control annual and abnormal floods. In Sind, for example, there are hundreds of kilometers of single and double lines of embankments (Framji and Garg 1976). Some of the settlements of the Indus Valley Civilization, dating back to 3000–1500 BC, had water harvesting and drainage systems. The most recent to come to light are the settlements at Dholavira, a major site of the Harappan or Indus Valley Civilization, located in the Great Runn of Kutch in Gujarat. The inhabitants of Dholavira fashioned several reservoirs to collect monsoon runoff flowing in the flanking streams of the Manhar and Mansar. These bunds or dams raised across the streams are evocative of the gabarbands of Baluchistan. The purpose of these gabarbands was mostly to collect a “layer of alluvial soil over dry and barren rock, combined with the retention and economic control of distribution of flood water” (E. Hughes-Buller 1906; Agarwal and Narain 1997). Some evidence of irrigation in the Indian subcontinent dates back to the beginning of the third millennium BC when farming communities in Baluchistan impounded rainwater to use in their fields. Dams made of stone rubble have been found in Baluchistan and Kutch. Excellent water supply and sewage disposal systems were well-known features of these cultures. The standard of their hydro-technical infrastructure was not equaled even 2,000 years later by the Romans whose water systems are generally considered outstanding. As in Mesopotamia, protection against annual flooding of the Indus River, irrigation to secure and increase crop yield, and drainage of large alluvial areas were preconditions to the survival of kingdoms in the Indus valley (Agarwal and Narain 1997). According to Leopold et al. (1964), silt accumulation in alluvial areas of the Indus River at Mohenjodaro are of the same order of magnitude (about 33 feet) as that found by archaeological soundings in other alluvial areas during the last 5000 years.

Indian scriptures are rich in examples of human attempts to undertake rational water harvesting measures. The scriptures also refer to the significance of water bodies, natural or artificial, during war. The *Puranas, Mahabharata, Ramayana* and various *Vedic* scriptures make multiple references to canals, tanks, embankments and wells (ICAR 1964). Among the scriptures, the Vedas are the oldest and the Vedic period extends between 2000 and 800 BC (Chattopadhyay 1990). These early Hindu texts, written around 800–600 BC reveal certain knowledge of hydrological relationships. The Vedic hymns, particularly those in the *Rig Veda*, contain many notes on irrigated agriculture, river courses, dykes, water reservoirs, wells, and water lifting structures.

The Rig Veda (2000–1500 BC, an ancient sacred book of wisdom) uses a term *Avata* to signify a well. The dictionary of Nighanta mentions fourteen types of well. At the same time, there are mentions of *Kulya* an artificial river or canal. In another passage, there is a reference to a dried up reservoir. The *Yayuraveda* also refers to canals and dams which were known as Kulya and *Sarasi*. Sarasi, in fact, denotes an artificial reservoir and a natural lake as well. The *Atharva Veda* (III, 13) gives a description of the construction of canals from rivers. A canal is fed by a river or, in other words, a canal takes off from a river. To convey this sense, the Atharva Veda describes a canal as a calf and the feeding river as a cow (Sarava 1954). The Chandogya, one of the principal *Upanishads* (the philosophical reflections of the Vedas, numbering 108 in all), points out (Garbrecht 1985 as cited in Agarwal and Narain 1997, p. 13): "The rivers. . .all discharge their waters into the sea. They lead from sea to sea, the clouds raise them to the sky as vapour and release them in the form of rain. . ..". This is probably the oldest reference to the natural processes within the hydrological cycle. It shows that as early as about 1000 BC attempts were being made to interpret and explain recurrent natural phenomena on the basis of direct knowledge. The linkage between the environment and the water system was understood even at the time of the Greek Philosopher Plato (427–347 BC) who has written a vivid description of erosion he observed at Attica in Greece.

Manu, the first man and the legendary author of an important Sanskrit code of law, the *Manu-Smrti* (second century AD), prescribes a punishment of death for a person causing a breach in a dam. He also writes in his work (VII. 196) that a king, wishing to conquer his enemy, should first destroy all types of dams (tataka) in his territory (Sarava 1954). Bishnugupta Kautilya (third century BC), the prime minister of the King Chandragupta Maurya (321–297 BC), in his Arthasastra or book on polity, gives the same advice i.e., during war the land of the enemy should be flooded by breaking or breaching lakes, dams and embankments (Sarava 1954; Bhattacharyya 1998). The purpose behind such practices was to disrupt the transportation system so that enemies could not move through the flooded terrain. Similar steps used to be taken by the Chinese. During war, enemy lands were flooded by forced breaching of dykes and dams (Schnitter 1994). With a similar purpose, even now, river bridges are destroyed during war. Ramayana, the first Hindu epic (before fifth century BC) describes in detail several advanced engineering works. Valmiki, the author of this epic, gives an account of how King Bhagiratha and his group of engineers diverted the course of the Ganga from the Himalayas towards the present Ganga delta.

The acquisition and protection of state territories, for which Kautilya required finance is the central theme of the Arthasastra and this was Kautilya's major concern. Kautilya, therefore, looked for agriculture as a source of state revenue.

Kautilya's book confirms that the people were acquainted with rainfall regimes, soil types and suitable irrigation techniques in specific micro-ecological contexts. In his book, he gives detailed instructions on exemptions from taxes, fines for misuse of water from the dams, and failure to renovate or maintain the tanks or structures based on rivers. The Arthasastra says that the ideal distribution of annual rainfall should be one-third of the annual rainfall in the first and the last months and two-thirds in the intervening months (Kangle 1969; Agarwal and Narain 1997).

Indian historical records and reports are full of descriptions of such water management policies and programs (Bhattacharyya 1998). The inscription of Rudradaman I on the Girner Rock in Kathiawar records the construction and repairs of Lake Sudarsana by successive viceroys of the Maurya Chandragupta (321–297 BC) and perfected under the Maurya emperor Asoka (260–222 BC) (Kotriah 1959).

In his report, Willcocks, an Egyptian engineer, writes that many of the distributaries of the Lower Ganga are nothing but artificial canals modified by natural riverine processes (Willcocks 1930). The Lower Bengal was inhabited by very advanced people known as Gangarides or Gangaridaes (Basu 1989) and it was reported by Megasthenes, an ambassador of Alexander, that the Ganga valley, ruled by an emperor known as Chandragupta Maurya (Brittain 1958), was occupied by highly civilized people who practiced irrigation with a skill at least equal to anything known in Mesopotamia. It was not unnatural for a highly civilized agrarian society to construct artificial canals for irrigation purposes. The system of overflow irrigation was very popular in India's richest agricultural area, the flood plain of Bengal in the pre-British period. People here developed indigenous techniques to use the threatening flood water of the rivers Ganga, and Damodar along with monsoon rainfall to irrigate and fertilize fields. This water was also used to control diseases such as malaria by allowing the fish in the flood water or rice field to eat away the mosquito larvae. William Willcocks studied the system in the early part of the twentieth century and reported, "This system is as perfectly suited to meet the special needs of Bengal as "basin irrigation" suits those of Egypt or "perennial irrigation" meets those of Babylonia" (Willcocks 1930, p. 4). This system of overflow irrigation was properly controlled. It enriched the soil, ensured a supply of water to every individual field and checked malaria (Willcocks 1930; Bhattacharyya 1998, 2000).

In Lower Bengal, the history of embankments predates the British period (Willcocks 1930) and there were extensive embankment systems prior to British rule. There are volumes of reports on the Bengal embankments published during the British era containing papers from 1852 to 1923 (Voorduin 1947; Bhattacharyya 1998, 1999–2000a). In Bihar, there were artificial cuts on river levees or canal banks. These cuts were known as Kanwas in Bhagalpur of Bihar. The word Kanwas is derived from the word "Kan", an old Persian or Arabic word meaning "to dig". These cuts were made for overflow irrigation in Bengal (Willcocks 1930; Bhattacharyya 1998, 1999–2000a). According to Willcocks (1930), the Chola Kings who lived in Bengal about 2,000 years ago (probably first century BC) were the inheritors of this system of irrigation which they took with them to the Tanjore delta when they conquered the extreme southern part of the Indian peninsula. In South

India, these early Chola Kings (first century AD) were pioneers in the construction of reservoirs. The River Cauvery was a flood-prone river and the king Karikala I first introduced the concept of flood control measures by constructing dams and embankments (Sarava 1954). The construction of a dam by Karikola is mentioned in an inscription of the Saka year 1277 (1355 AD) (Saka Calendar is a lunar calendar originally from South India and it was brought to Indonesia around 465 AD. One Saka year has 12 month and each month ends on a new moon). During the reigns of the Chalukya, Hoyasala and Kakatiya rulers (twelfth century AD), several tanks and a few anicuts were constructed. This policy continued during the Vijayanagar period between 1336 and 1564 AD when great emphasis was placed on developing irrigation facilities for the improvement of agriculture (Kotriah 1959; Bhattacharyya 1998).

Water has been harvested in different places of India since antiquity and many places show evidence of advanced water harvesting systems. The Bhopal Lake created in the eleventh century (1010–1055 AD) was one of the largest artificial lakes of the Indian Peninsula covering an area of over 650 km^2 (Schnitter 1967). The twelfth century (1148–1150 AD) chronicle of Kashmir, Kalhana's Rajatarangini, describes a well-maintained irrigation system in which notable structures existed around the Dal and Anchar lakes and the Nandi canal. Ganapati (1973) reports that almost all the major and minor rivers and their tributaries have been dammed in South India to form human-made lakes. In the eastern states of West Bengal and Orrisa, "pond" and "tank" are interchangeable expressions, while in states like Andhra Pradesh, Karnataka and Tamil Nadu, tanks refer to a section of irrigation reservoirs including small and medium sized water bodies.

Ceylon (present Sri Lanka) also has evidence of human's effort to control water resources by control measures. For example, the Minneriya tank was constructed by the King Mahasena in the third century BC. The embankments date back to 370 BC (Schnitter 1994). The inhabitants were very careful in handling the liquid resources and the tanks were built in an orderly way at slightly varying elevations so that there was a series of reservoirs to take the overflow from the one above it. The exit of water was controlled by means of sluices to the rice fields (Brohier 1934a, Part I, p. 3). Reservoirs for irrigation have been introduced from the ancient period for rice cultivation. Sri Lanka abounded in canals strongly bunded; it had a bund with a volume of over 17 million cubic yards (Agarwal and Narain 1997). But warfare and malaria subsequently obliterated the irrigation communities and most of the earthworks were breached and overgrown with forest (Brohier 1934a, b, Parts I and II; Pereira 1973).

In adjacent Burma, present Myanmar, the Irrawady shows extensive embankment systems which are quite old in origin. In this system, the alignment of the embankment was in a horseshoe pattern around the areas between the river distributaries so as to leave the downstream ends of the compartment open. In the event of extreme floods, the lower portion of the embankment acted as a flood basin thus reducing, though slightly, the flood peaks. The system of open embankments could be a compromise solution to the controversy surrounding flood protection by dyking in any deltaic area (Volkar 1964; Bhattacharyya 1998).

In China, emperor Yau constructed dams and dykes in 2280 BC. There is an ancient Hongze reservoir in central China. The Chinese subjects used to assess their emperors as good or bad on the basis of waterway maintenance measures adopted by the rulers (Biswas 1970). Dykes and canals were in existence in the upper reaches of the Hwang Ho (Yellow) River in 603 BC. It is a well-known fact that the Hwang Ho River was notorious for its flood disasters with the first flood recorded in 2297 BC (Hoyt and Langbein 1955). In later years, the concept of flood zoning also developed in China. In 8 BC J. Chia, the highest authority in charge of the Hwang Ho River, prepared a flood control plan. He recommended abandoning the densely populated foreshore and resettling the people somewhere else. The primary purpose behind his plan was to keep enough space for flood flow. Another purpose, of course, was to save people from flood disaster. Reclamation of flood-prone areas for agriculture was in practice nearly 4,000 years ago in the same Hwang Ho plain. In order to reduce vertical erosion, rivers were confined within close lateral dykes. This system was known as Loute and it was invented by C.H. Pan between 1521 and 1595. Together with these close or loute dykes, Yaote or distant dykes used to accommodate flood waters were common (Framji and Garg 1976). The major floods in the Chang Jiang (Yangtze River) are well documented in inscriptions and flood marks (Luo Cheng-zheng 1985).

Moving from tropical to temperate countries, we find that the history of reservoirs in Europe goes back over 200 years. The use of dykes in the Po valley of Italy is quite ancient (Framji and Garg 1976). Unlike tropical Asia, the history of control structures in the USA is relatively recent. The Anasazi constructed small check dams on the Colorado River in Mesa Verde 800 years ago to hold storm runoff for later use on their crops (Ortiz 1979). The first levees, 1.2 m high on the Lower Mississippi, were constructed in 1717 when the city of New Orleans was founded. The Mississippi and its major tributaries now have one of the most extensive embankment systems in the world.

These few examples of river regulation from all over the world and from Asia in particular indicate that, from the very beginning of civilization, river water was put to human use and rivers had to be trained for the socio-economic benefit of society. With the first human settlements about 7,000 years ago began a two-fold struggle with water. On the one hand, people had to protect themselves against floods; on the other hand, they had to ensure a safe water supply for domestic use and irrigation. As a consequence, hydro-technical installations were among the earliest technological achievements of humankind (Agarwal and Narain 1997). Antecedent to the river training programs, observation on the behavior of the target river was imperative. Observation was followed by an analysis of river behavior and the final step was the construction of various artifacts to meet specific objectives. In a contemporary geomorphic language and sense as well this was the beginning of applied geomorphology that is application of geomorphic knowledge to solve socio-economic problems.

River regulation represents a natural and prerequisite condition of civilization (Wittfogel 1956; James and Marcus 2006). This is the cardinal factor

behind selection of the research theme, which focuses on applied geomorphological and human-environmental issues connected with river control structures.

The need to apply scientific knowledge for economic and social benefit has been strongly felt in decolonized developing countries in the tropics since the early nineteen forties. To feed growing populations, planning objectives in newly independent countries of Latin America, Africa and Asia included the exploration of native resource potential so as to lessen dependence on foreign assistance. Scientists were requested to use their theoretical knowledge to solve practical problems. As a part of planning policy, the resource which was developed first was river water and almost all major rivers in decolonized Latin American, Asian and African countries are now controlled, though in different phases. Thus river water utilization and river control structures are now two of the major issues in developing countries in the tropics. India is one of these countries where harnessing of river water resources received top priority in planning programs just after independence in 1947.

The purpose is, therefore, to select a theme, which has national significance, and a theme, which is relevant at international level as decolonization is a continuous process, and river training policies and programs are still crucial issues in all countries (Petts 1984; Bhattacharyya 1998).

Ancient civilizations developed in the flood plains as has been mentioned earlier. But are we aware of the fact that the riverbed itself is often a site for human settlement? In tropical Africa and Asia, alluvial bars are used for agriculture in case of seasonal rivers when bars are exposed due to lowering of the river level. This is a common practice throughout the Indian sub-continent. Emergence and submergence of riverine bars, particularly in the deltaic tract, are common phenomena and there are often disputes over the occupation of these bars particularly in the border districts and states. For reasons that are obvious, the riverine bars are preferred sites for agriculture, though the extent of the agricultural season depends on the survival potentiality of these bars. These bars have also provided temporary shelter for war victims (Semple 1911). These sandbars are used as campsites in the Colorado River (Schmidt and Graf 1990). About 219 sandbars in the Colorado River between Glen Canyon Dam and Diamond Creek provide a fertile environment for biological life and many of the sand bars are used for public recreation (Budhu and Gobin 1994). It has been noticed that throughout West Bengal, India the riverine alluvial bars provide shelter for millions, most of whom are Bangladeshi refugees who came from the erstwhile East Pakistan (present Bangladesh) after 1947 and again during the Bangladesh war in 1970. They are not only political and economic victims but also social victims. A sizeable number of these refugees who came from the farming sector rejected government-sponsored refugee colonies where they would be doomed to a dole-sustained existence. They preferred the riverine islands in the Ajay, Damodar, Hooghly-Bhagirathi, and even Mahanadi for self-sought settlements. These rivers are now dotted with such settlements some of which are quite prosperous (Basu 1988; Bhattacharyya 1999, 1999–2000b, 2008b). The alluvial sand bars are also inhabited by displaced people from flood-affected

West Bengal. The control structures on these rivers have brought several changes to the riverbed environment and the refugees and local displaced people are constantly struggling with this changed environment for their survival (Bhattacharyya 1999, 2008b). Moreover, the refugee problem, which started almost 50 years ago, still plays a crucial role in Indian politics, particularly in the eastern part of the country where constant infiltration of Bangladeshi refugees in the Border States creates political tension. The problem is aggravated when the question of granting of "patta" or land deeds in the self-sought settlements comes to the forefront. The question has taken on greater significance in the Damodar Valley Corporation (DVC) command area where there are several self-sought refugee settlements in the riverine sandbars.

For selecting the research theme and the research area these questions and their magnitudes were pondered over. These are the distinctive facets of the purpose behind the research theme.

The decade of the 1990s was declared the International Decade for Natural Disaster Reduction (IDNDR) and this IDNDR forced people to refocus their attention on hazardous processes such as floods and cyclones. It is sad to state that, despite tremendous improvement in technology and a revolution in information technology, people all over the world, not necessarily only in the tropics, are still affected by floods, droughts, hurricane, earthquakes and other natural disasters. Floods are of universal concern and reference to them is found in the mythology of all religions, in traditional anecdotes, and in historical records. The evidence of deluge is found in the Biblical story of Noah. There are clear parallel example in Hebrew and Babylonian traditions (Lambert and Millard 1969; Ward 1978). In India, the *Satapatha Brahmana* (sixth century, BC), an important treatise on sacred rituals, makes a reference to a devastating flood and how Manu, a glorious sage, saved mankind from that flood (Shastri 1950).

Therefore flooding, an issue of mythological, traditional and contemporary relevance was included as part of the research theme. Moreover, flooding is an issue which stands at the interface between theoretical geomorphology and applied geomorphology.

The modern history of River Basin Planning can be traced back to two major developments that took place in the 1930s. The first was the formation of the Tennessee Valley Authority (TVA) in the United States in 1934 and the second was the presidential address given at India's National Institute of Sciences in 1938 by notable Indian physicist and planner, Meghnad Saha (Saha and Barrow 1981). After 1947, throughout India, several rivers have been trained to reduce flood risk. Several multipurpose projects have come up and dams have been constructed like the Maithon, Panchet, Tilaiya and Konar on the Damodar and its tributaries. The Bhakra Nangal on the Sutlej, the Hirakund on the Mahanadi, Tungabhadra, on a tributary of the Krishna, the Chambal reservoir on the Chambal, and the Kosi reservoir on the Kosi have been completed. In India, River Basin Organizations (RBOs) first emerged as a mechanism for integrated planning of large projects, especially as a means of balancing the requirements for power, agriculture, flood-proofing and industry. One such RBO, the DVC, came into existence in 1948 along the lines of the Tennessee Valley Authority, USA (Chandra 2003; Pangare et al. 2009). The fully integrated development of entire basins was subsequently pursued in many basins throughout the world, notably in the Volga River Basin, USSR and in the Snowy Mountains scheme of Australia (White 1977).

In recent history, the Tehri Dam on the Bhagirathi River is expected to be higher than the Bhakra. As far as reservoirs are concerned, several dams such as the Sriram Sagar, Srisailam and Sardar Sarovar on the Narmada exceed the Hirakud in size (Rangachari et al. 2000). India's most ambitious project, the interlinking of peninsular rivers is also referred to as "inter-basin transfers" i.e., water transfers from the "surplus" basins to the "deficit" basins (Iyer 2002). In 2007 the Supreme Court of India ordered the national government to proceed with the hydrologic interlinking of all of the subcontinents major river basins. If implemented, it would augment lean season flow in the lower riparian country, moderate floods, mitigate droughts, turn parched areas into fertile land, create millions of jobs and promote hydropower (Prabhu 2003; Sarkar 2003). Critics of this project point out that it would bring severe environmental ecological and social consequences (Ghosh 2003; D'Souza 2003; Thakkar 2003; Ray 2003). This riverlinking project is also viewed as an extremely cost-effective measure for the expansion of an efficient traditional irrigation system (Bandyopadhyay and Perveen 2004). The USA, a water rich and scarcely populated country is transferring 45 billion m^3 (BCM) of water through inter-basin transfer and planning to add 376 BCM. In Canada, the existing schemes have been designed to transfer 268 BCM. China has a scheme under implementation to transfer about 45 BCM. India, in comparison, transfers 10 BCM through the existing schemes and is planning to add about 200 BCM. So India is already late in implementation of water transfer links as mentioned by Suresh P. Prabhu, former Chairman, Task Force on Interlinking of Rivers (Prabhu 2003).

Despite extensive river control measures, floods still visit India. Some of the reservoirs in India have raised crucial political issues. S.L. Bahuguna, a social activist, was agitating against the construction of the Tehri dam in the Ganga-Jamuna Valley. Very recently, a large number of religious leaders and former IIT Professor AD Agarwal had been protesting against the proposed Loharinag Pala dam on Uttarakhand and claiming that it will threaten the existence of the river and block free flow of the Ganga. A group of ministers (GoM) announced they would scrap the project completely to ensure a free flow (The Economic Times 2010). A water sharing dispute has been going on for decades between the two states of Karnataka and Tamil Nadu. The government of Karnataka is raising the height of the Almati Dam and it is feared that after the completion of the project Tamil Nadu will receive a lesser amount of water which will ultimately affect the interest of farmers in the state. At the center of current tensions between the two states is Tamil Nadu's Hogenakkal Fall drinking water project on the Cauvery River. Similar questions have been raised regarding other reservoirs and barrages as well. For example, Boro cultivation in West Bengal to a great extent depends on the release of water from the Tenughat reservoir on the Damodar Valley in Jharkhand (Bihar) during drought years. If there is a lack of understanding between these two states the Boro cultivators have to suffer. Moreover, if there is a sudden release of water from the Tenughat, the lower reach of the Damodar gets flooded. During the monsoon season releases from this dam affect the operation of the Panchet reservoir as the Tenughat dam is the uppermost dam in the Damodar Catchment (CWC 2001).

These political issues have taken on very strong social nuances. Ms. Medha Patkar, a well-known social activist, supports the movement against the Narmada Valley Development program which is an overall master plan for building 30 major and 130 or more medium dams to harness the largest west-flowing river on the subcontinent for hydropower as well as for irrigation and regulation of seasonal flows. According to critics, the entire project will cause involuntary resettlement of over one million people without actually delivering the promised benefits. A World Bank sponsored environmental impact report on the Sardar Sarovar and Narmada Sagar complex (Dixon et al. 1989, p. 39; Levenhagen 1987) reported that "the major and continuing degradation of land and water resources in both project areas, (is) largely due to overpopulation and poverty. The projects should help alleviate some of these problems, although they will create others, especially in terms of resettlement". On the other hand, a concise description of the Narmada projects written by Mr. Christoph Dlewald reported, "there are major economic benefits from the Narmada project and associated environmental and social concerns" (Dixon et al. 1989, p. 39). It is also stated that the availability of water from the Sardar Sarovar Project will benefit about 191,000 people who live in 124 villages in arid and drought-prone border areas of Jalore and Barmer Districts of Rajasthan and have been suffering grave hardship on account of the dearth of water and the extent of the desert increasing every year (The Economic Times 2001). The Bhakra-Nangal project, described by first Prime Minister Jawaharlal Nehru as a modern temple of resurgent India, is a legend of India's developmental history. The "success" of Bhakra dam is used to justify most large dam projects in India and is often used as the last word in any debate or discussion related to the impacts, benefits and desirability of water management in the country. Even this iconic project, however, has come under attack in recent years. Shripad Dharmadhikary (2005) stated that the agriculture revolution of Punjab and Haryana is unsustainable even if one accepted the inevitability of the agricultural revolution, the primary drivers of which were HYV seeds, fertilizers, pesticides, and groundwater resources. The Dharmadhikary study, however, has been critiqued by Prof. V. Ranganathan as lacking in a rigorous approach to cost-benefit analysis and being extremely one-sided. He highlighted the need for big dams by citing the case of developed countries, where over 90% of hydro power potential has been exploited. It was stated that the essential question was how to improve management of dams and not necessarily shun them (Rangachari 2006).

These questions are socio-economically relevant, not only in India but in adjacent countries as well. The most controversial international issue between India and Bangladesh is the issue of the Farakka Barrage. The Farakka Barrage was constructed in 1970 in order to divert part of the Ganges into the Bhagirathi-Hooghly to save Calcutta port. It was presumed this barrage would reduce flood risk in the Lower Padma. But instead, the Bangladesh Government has a feeling that because of the Farakka Barrage the Padma is not getting adequate water from upstream in lean periods and that the flood propensity has increased due to shallowing of the river.

In 1996 there was an agreement that more water would be given to Bangladesh. However, future success in the implementation of this agreement depends entirely on political perceptions and not on technical solutions (Reddy and Char 2001).

While selecting the research theme a question was addressed whether river training programs and river control structures ultimately solve social, economic problems for which these plans were executed and these structures were constructed.

The twenty-first century has been declared the age of water scarcity although flood losses continue to rise (Kundzewicz and Kaczmarek 2000). In spite of extensive flood control measures, flooding is still a major issue in a tropical country be it developed, developing or under-developed. The effects of Hurricane Katrina in New Orleans on August 29, 2005 were devastating and long-lasting. It was labeled the most devastating disaster in American history; unprecedented and resulting in record high financial losses. The great flood of 1993 in the Midwest, USA has been labeled a hydrometeorological event unprecedented in recent times (IFMRC 1994; Kundzewicz and Kaczmarek 2000). The damage was extreme in some places due to extensive development of the flood plain. At some locations, the 1993 flood ranked as a once-in-100-year event and in other locations it challenged the once-in-500-year event design flood model (Changnon 1993). Bhowmik (1993, p. 130) reported "The main lesson from this event is that it is environmentally and economically better to work with a river than to work against it. The river can and will reclaim its flood plains whenever conditions are just right". In 1995, 250,000 people had to be evacuated in Netherlands when flood water on the Rhine River threatened the dyke (Begum et al. 2007). In 1996, half a million people had to be evacuated in order to repair a breached dyke along the Yangtze River and its tributary due to unusual floods in the month of June 1996 (The Telegraph 1996). In South Asia, even today, we are faced with newspaper headlines asserting that "Hundreds killed, millions stranded by floods in India and Bangladesh" and "What caused the floods and why Indus so flood-prone?" (Report 2000; Bosshard 2010). In 2008, the Kosi River created panic during monsoon season and Bihar was in the headlines (Priyadarshi 2008). In 2009 the flood water submerged the Krishna and Tungabhadra rivers and the Karnataka government released up to 67,968 cumecs[1] (24 lakh cusec) of water from the Almatti and Narayanpur dams in a single day. In August 2010, flooding in Pakistan, affected 17 million of its 167 million people.

These few examples show how catastrophic floods continue to play havoc in the lives of people all over the world. Thus, in assessing the benefits and risks of having dams, their significant role in mitigating the effects of floods should not be underestimated. The drought in the northwest in 2000 and floods in the Kosi River in the year 2008 prompted a far-reaching discussion of fundamental approaches to flood and water resource management and use in the country including the role

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[1] Cumec is a metric unit of measurement for water discharge. It stands for a cubic meter of water passing through any given point per second. There are 35.31 cusec to every cumec.

of all levels of government and local riparian communities in the decision-making processes.

Since 1969–1970 the globally acclaimed concept of Environmental Impact Assessment (EIA) and, since 2001, the so called Strategic Environmental Assessment (SEA) of the European Union are being applied for large engineering projects. Any research venture we believe should have some significance not only at local, regional or national level but also at international level.

Floods have been a worldwide concern throughout history and today, together with unprecedented climate change leading to severity of flood and drought in some areas, remain an international concern. Therefore sustainable water resource management has been selected as a research theme for this study.

Dams were once hailed as great symbols of progress and of the power of people to harness nature for the good of humanity. About 45,000 large dams have been built around the world in the last century (ICOLD 1998). More than 1,500 large and medium-sized dams are in India and 100 barrages on all major river systems (Gopal 2000). Such engineering devices on river systems have raised questions with social, economic and political significance (Dharmadhikary et al. 2005, 2008). In many cases, it has been alleged that rural communities have been displaced by rising water upstream or have been denied sufficient water downstream. Many have questioned whether some control structures like dams and barrages augment the resource potential or enhance the hazard propensity of floods.

Beginning in 1997, decommissioning of large dams in the United States has exceeded their construction rate (Keller et al. 2000). Between July 1997 and July 1998, the Secretary of the United States Department of Interior, Bruce Babbitt decommissioned six large dams (Babbitt 1998). The removal of two dams from Washington's Elwha River will be one of the most significant restoration projects in recent time. Two hydroelectric dam construction in the early 1900s resulted in the loss of approximately 95% of the anadromous salmon spawning habitat on the river (Warrick et al. 2005). Removal of dams in Elwha is like destruction in the name of creation. While nearly 450 dams have been removed in the United States, there are few published studies documenting post-dam removal effects. The acknowledgement of the potential costs of future dam removal as well as sediment management may make other options of water supply like ground water storage and off stream reservoirs more competitive (Minear 2002).

The intense social and environmental debate over large dams led to the establishment of the World Commission on Dams (WCD) in 1998. WCD prepared country review studies for India and China. However, in the report, WCD has sidelined a number of key issues and the related problems that developing countries like India face (Navalawala 2001). In reference to the World Commission on Dams final report "Dams and Development – A New Framework for Decision Making" launched on 16th November 2000 at London, the Government of India, Ministry of Water Resources has rightly rejected the draft of the India Country Report. A Sekhar, Commissioner, Government of India, Ministry of Water Resources stated "On a detailed perusal of the Final Report it is seen that WCD has leaned heavily on the Consultants Country Report, totally ignoring government's view on the report and the data on the successful projects in India furnished by us to WCD. The references relating to India in the report are not based on factual and authentic information".

Water resource issues facing India are very different from those in other developed countries. In India there is spatial and temporal variation in rainfall and rainwater needs to be stored properly for efficient use. Small dam and rainfall harvesting is possible where the population is dispersed and there is a reasonable amount of annual rainfall. A series of smaller dams, even if feasible, would involve higher costs, greater submergence, far more displacement, greater evaporation losses, increased maintenance and far less benefits (CBIP 1987; The Economic Times 2001). Therefore monsoon countries like India require large-scale storage in order to assure the necessary food supply, employment and electricity generation, ecosystem conservation and mitigation of adverse impacts of floods and droughts. The question is not whether dams are necessary, but rather how these can be constructed and managed, where essential, so that the overall benefits to the society are maximized (Biswas and Tortajada 2002).

Environmental concerns worldwide have become more urgent than ever before and one of the most controversial aspects of this has been the human role and its impact on fluvial systems and on the socioeconomic environment. Geomorphologists, planners and Scientists following the lead of G. P. Marsh (1864) have historically tended to examine the effect of a range of anthropogenic changes on the riverine environments (Thomas 1956; Strahler 1956; Wolman 1967; Schumn 1969; Graf 1977, 2006; Gregory 1977, 2006; Goudie 1989, Goudie 2006a, b; Meybeck and Vörösmarty 2004; Vörösmarty et al. 2004; Kondolf et al. 2007; Naiman et al. 2005; James and Marcus 2006; Wohl 2004, 2006; Wohl et al. 2009; Braatne et al. 2008; Montgomery 2008; Bhattacharyya 1998, 1999–2000a, 1999–2000b, 2008b, 2009). M. Gordon (Reds) Wolman from Johns Hopkins University, commenting on riverbed settlers in the Damodar River, wrote (personal communication dated April 10, 1996, January 11, 2007) that controlled releases can minimize the rate of flooding in spite of canalizing common floods in other ways. "How much water can you release from the dams upstream, assuming controlled releases are possible without excessive flooding of the populated islands while still maintaining sufficient channel capacity to carry many common floods of frequent recurrence? I assume that the biggest floods requiring use of spillways on the dam will result in flooding the islands in any case. Simply put, is there a set of design flow releases that will at least reduce frequent flooding?" He continued, "it is remarkable the way in which immigrants unfamiliar with the riverine environment adapted to the altered hydrologic regime of the regulated Damodar River settling on and modifying the alluvial bars." Anthropogenic processes of the kind within riverbed *Char* lands/*Mana*[2] remarked on by Reds Wolman has not been adequately studied by geographers.

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[2] All types of sandbars are referred to as *Char* in Bengali. In Bangladesh Chars are locally known as *Mana* derived from Mohana which usually denotes a confluence of river and sea. The sandbars in the Damodar would have remained as uncultivable waste land had there been no population transfer between India and erstwhile Pakistan (presently Bangladesh) between 1947 and 1971 following Independence and Bangladesh war respectively (Bhattacharyya 1998, 1999–2000b).

According to James and Marcus (2006), “The lack of a priori model on anthropogeomorphic change, however, presents a challenge for the next generation of geomorphologists with this rapidly growing subfield”. They continued that we need to enrich our understanding of how humans alter rivers (James and Marcus 2006) and at the same time how to protect and care for the river system through presence of floods, dams and community involvement. The drastic alteration of World’s river systems has received much less attention than global climatic change, and it has been suggested that “the global impact of direct human intervention in the terrestrial water cycle (through land cover change, urbanization, industrialization, and water resources development) is likely to surpass that of recent or anticipated climatic change, at least over decadal time scales” (Meyback and Vörösmarty 2004; Vörösmarty et al. 2004).

This is yet another purpose behind selecting a research theme which focuses on the engineering structures on a river and human impact on fluvial environments.

From this perspective, a review of the first Indian multipurpose river valley project and its human and environmental impact through construction of control structures is timely.

1.2 Perspectives

Floods, flood control measures and physical and socio-economic significance of such measures are examined by several disciplines such as geography, sociology, economics, hydrology, and engineering sciences. Each addresses flood-related issues from a distinct disciplinary perspective. Geography is an observational or spatial science; therefore, the geographic perspective is a spatial perspective. All phenomena, physical and socio-economic are registered on this space, which is complex but concrete, coherent and predictable as well (Beaujeu–Garnier 1976). In other disciplines space enters tangentially or peripherally. In geography, space is the focusing center (Basu et al. 1995). The word space here refers to social space which is physical space with all its complexities and through which people living in it interacts, perceive, and adapt to their new-found resource base (Personal communication with Basu M, February 23, 1994). The questions raised, discussed and answered here are within the geographic perspective. Secondly, emphasis has been placed on the exogenetic landforms, land forming processes and materials. Here perspective is, therefore, a geomorphic perspective although the admission of anthropogenic forms, processes and materials in geomorphological enquiry has been acknowledged. Here the focus will be on issues which relate geomorphology to other disciplines. This is the perspective of applied geomorphology i.e., application of geomorphic knowledge in planning and managing the fluvial environment. All applied geomorphological questions, however, are addressed within a wider geographical perspective.

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Chapter 2
Introduction

Abstract The Damodar River, a subsystem of the Ganga River in India, exhibits most of the characteristics of a seasonal tropical river with a fluctuating regime. In this chapter, the author examines the Damodar valley region, focusing on the various factors that led her to select the applied geomorphological perspective as the most appropriate perspective for the study. In the absence of an a priori model to examine applied geomorphological and human environmental issues in a controlled riverbed, several concepts from inter-connected disciplines will be utilized to verify empirical facts. One of the objectives of this study is to explain land use characteristics and human perception, adaptability and resource evaluation on the riverbed in relation to human adjustment to floods and dams of the Lower Damodar. Therefore, a brief discussion of the concept of land, land resources and land use has been provided. Some concepts such as social space, perception, culture, refugee, human ecology, hazard, and empiricism, borrowed from sociology, anthropology, ecology, philosophy and similar disciplines, have been considered in explaining a human-modified fluvial environment.

Keywords Adaptability · Culture · Damodar River · Ecology · Perception · Resource evaluation · Social space

2.1 Geography of the Damodar River

The Damodar River, or the Deonad Nadi as it is known in its upstream sector, is a sub-system of the Ganges River system of India. In the Matsya Purana (a sixth century BC tract) the Damodar is named Mahagauri and has been described as a rocky River (Antasira) and a river that is difficult to encounter (Durgama) (Ali 1966; Bhattacharyya 1998, 2002). This description probably refers to the upstream bedrock-controlled Damodar. Ptolemy refers to this river as the Dharmadaya (Majumder-Sastri 1927; Sen 1962). Ancient cartographers, travelers and explorers have also referred to this river by different names. The local meaning of the

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word Damodar is “womb” or Udar, which is “full of fire”. This implies that the Damodar flows through a coal-rich area. The river rises in the Chhotanagpur watershed approximately at 23°37′N and 84°41′E and the geographical boundary of the basin lies between 22°15′ to 24°30′N latitude and 84°30′ to 88°15′E longitude. The entire drainage basin resembles a tadpole in shape with the head to the west. The main tributaries are the Barakar, Tilaiya, and Konar. Below the confluence of the Barakar and Damodar there are a few insignificant tributaries such as the Nunia and Sali. Once the main distributaries were the Khari, Banka, Behula, and Gangur, but now they look more like independent rivers. Near Palla the river takes a sharp southerly bend. Similar characteristics are to be observed in some other tributaries of the Hooghly-Bhagirathi such as the Mayurakshi. These sharp bends and deferred confluences with the Hooghly-Bhagirathi are explained as reflections of structural hinges (Sengupta 1972; Agarwal and Mitra 1991).

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). Old maps of Jao De Barros (1550), Blaev (1645), Vanden Broueke (1660), and Rennel (1779–1781), as well as other maps and charts of unknown cartographers show the changing courses of the Damodar below Barddhaman (Sen 1962). This part is referred to as the Damodar paradelta (Bagchi 1944) which is older than the Ganga-Brahmaputra delta. This study is mainly concerned with the reach of the Damodar River between Maithon and Panchet reservoirs and the old confluence point with the Hooghly River opposite of Falta (Fig. 2.1, Plate 2.1).

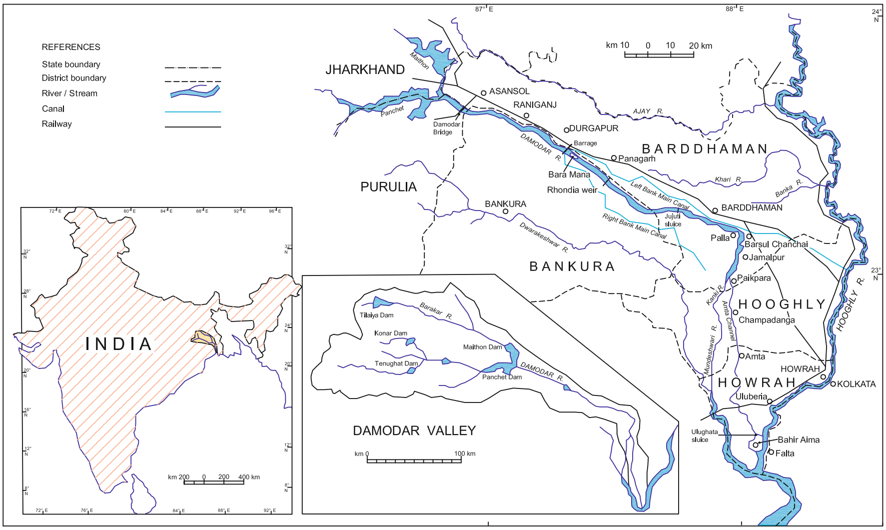

Fig. 2.1 Location of study area

2.2 Geological Set Up

In its upper sector, the Damodar flows through the quartz-rich Archaean gneiss. In its middle stretch lies the Raniganj coalfield, i.e., the Damodar flows through the sandstone-rich Gondwana sedimentaries near Asansol and Raniganj (Fig. 2.2).

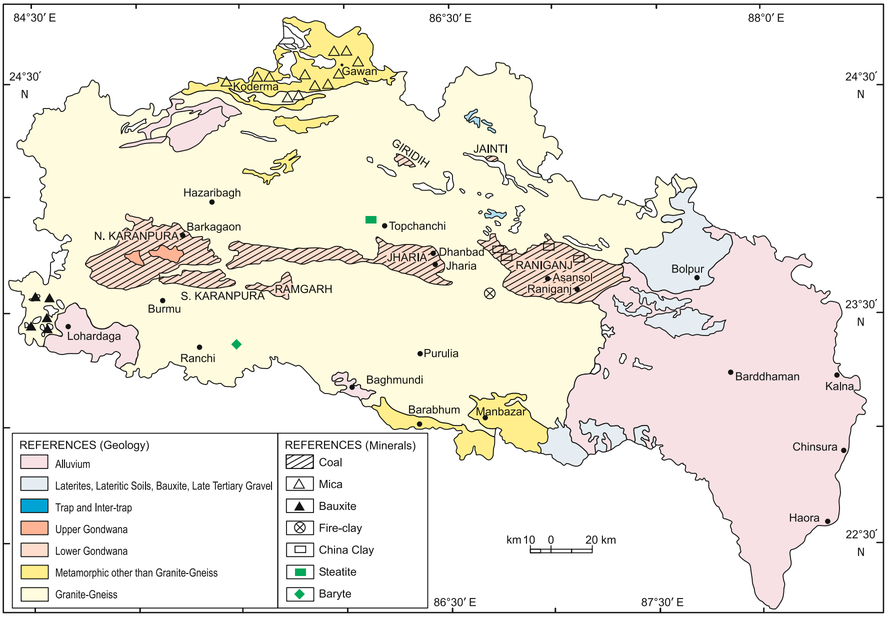

Fig. 2.2 Geology of Damodar valley region. Source: Chatterjee (1969)

2.3 Physiographic Divisions

The Damodar valley region can be divided into four physiographical regions (Fig. 2.3).

i. Eastern low alluvial plains.
ii. Central rolling plains.
iii. Central uplands.
iv. Western plateau and plateau fringe (referred to as Rarh plateau in West Bengal).

The eastern alluvial plain is also referred to as the *Rarh*[1] plain. It extends between the Bhagirathi Hooghly in the east and the 60 m contour line in the west. The Banka-Damodar plain lies within this physiographic division.

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[1] A region of West Bengal intervening between the western plateau and high lands bordering Chhotanagpur pleateau and the Ganga delta.

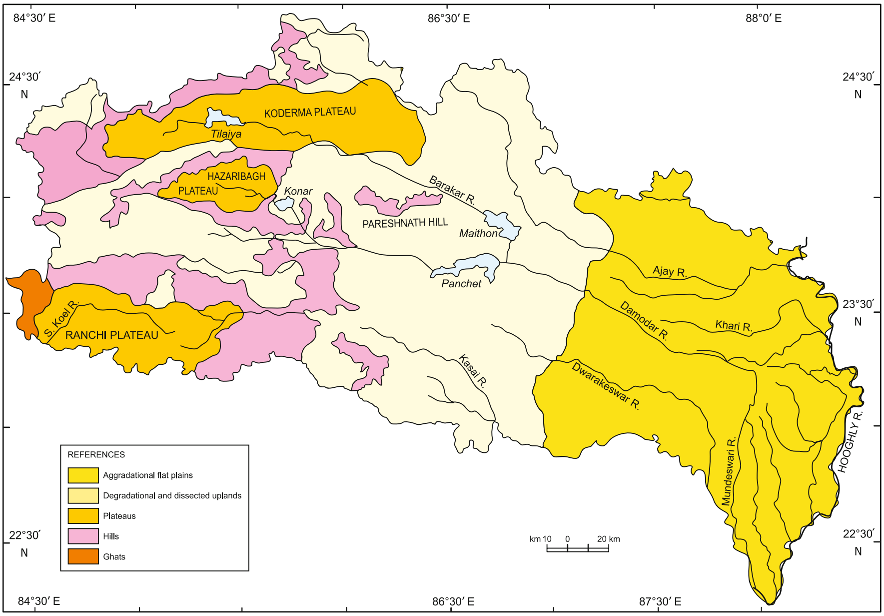

Fig. 2.3 Physiography of Damodar valley region. Source: Chatterjee (1969)

2.4 Soil

The soil ranges from skeletal plateau soil laterites to alluvial soil in its lower region. Near the Falta outfall the soil is slightly saline (Fig. 2.4).

2.5 Factors Behind Selection of the Lower Damodar as a Specific Studied Section

Since 1947 almost all major rivers of India have undergone extensive river training programs. A pertinent question, therefore, is why the Lower Damodar has been selected for this specific study. Prior to answering that question the Lower Damodar should be defined geomorphologically as throughout this present treatise, the stretch between the Panchet, Maithon reservoirs and the Falta point has been referred to as the "Lower Damodar" (Fig. 2.1, Plate 2.1).

Schumm's classical division of fluvial systems refers to Zone 1 as the source of sediment and water, Zone 2 as the zone of transfer of water and sediments and Zone 3 as the sediment sink or a zone of distribution and deposition (Schumm 1977). If Schumm's classification is to be followed, then the Lower Damodar should be taken from the off-take point of the Khari to the Falta point, as the Khari is the first important distributary of the Damodar. But at present, the Khari is no longer a distributary;

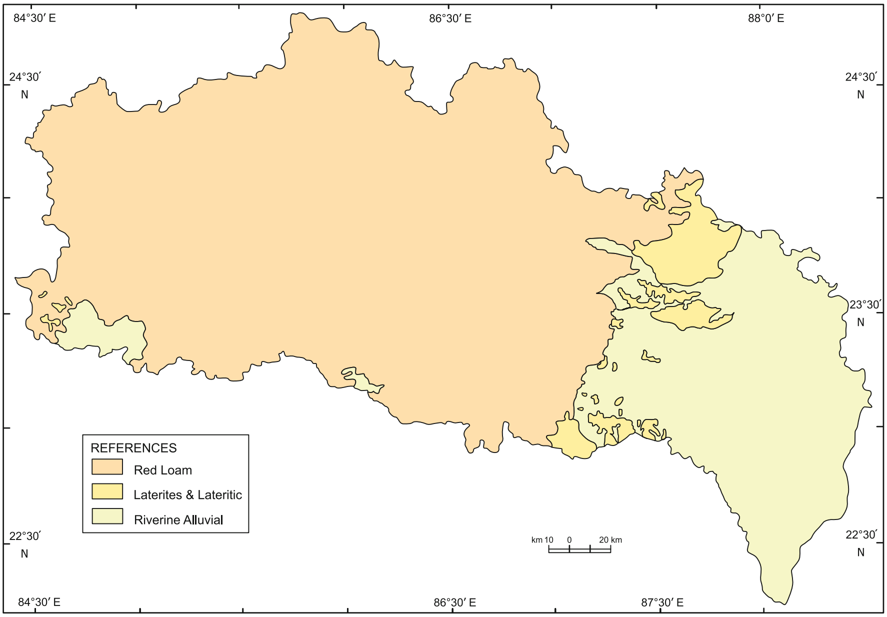

Fig. 2.4 Soil map of Damodar valley region. Source: Chatterjee (1969)

instead, it looks more like an independent river. That said, there are historical evidence that once the Khari, Banka, Behula and Gangur were distributaries in the old Damodar delta (Fig. 2.5). All these distributaries have been severed from the main river, most probably due to the construction of the south-eastern railway line and other roads. Therefore, the Lower Damodar is not delimited from the Khari off-take point.

If Schumm's scheme can be modified slightly, then the stretch below Jamalpur from where more important distributaries branch out should be defined as the Lower Damodar. Distributaries now appear on the map as the Kana Damodar, Kana *nadi* (small rivulet) and Kunti. The biggest or the largest distributary is the Mundeswari which, for various reasons, is treated as an independent river. But geographers such as S. C. Bose (1948) and S. P. Chatterjee (1969) have never referred to this stretch as the Lower Damodar. From the old maps, reports and the field survey, the off-take point of the Mundeswari appears to be an anthropogenic landform that will be discussed later in detail. Therefore, in the present study, the Lower Damodar has not been demarcated from the off-take point of the Mundeswari. P. K. Sen (1991) has delimited the Lower Damodar basin from the confluence of the Damodar and the Barakar near the Damodar bridge site near Barakar immediately below the confluence of the Damodar with the Barakar. Below the Damodar-Barakar confluence, there are a few insignificant tributaries such as the Sali, Nunia, and Tamlanala. In fact, the Damodar does not show a noticeable middle stretch or Zone II if Schumm's scheme is accepted.

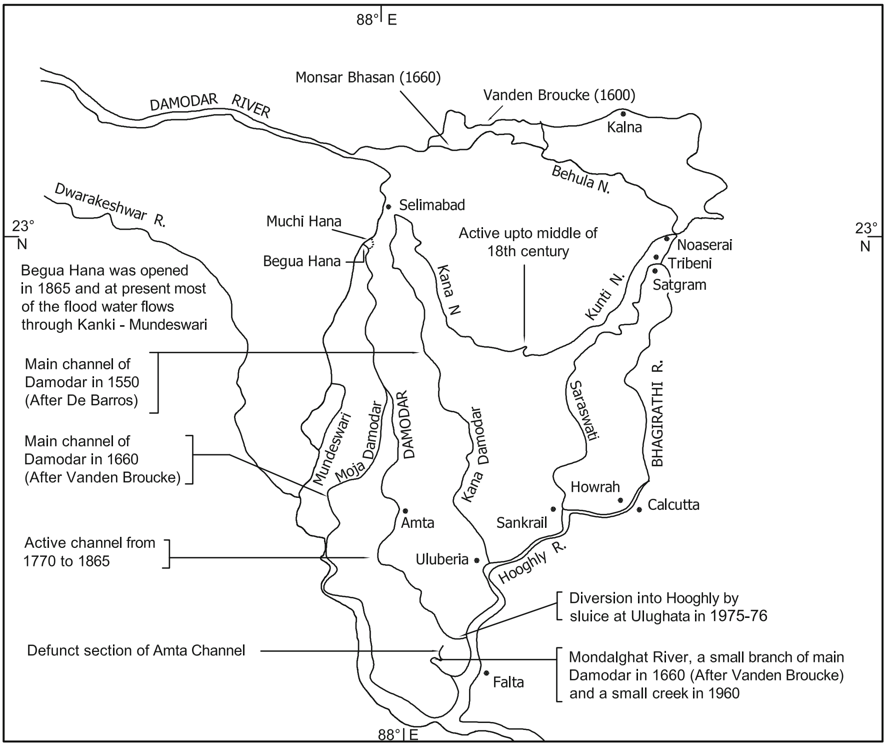

Fig. 2.5 Changing courses of Lower Damodar. (after Sen 1962; Basu 1889; Bhattacharyya 1998, 2002)

J. Choudhury (1990, 1991) divides the Damodar into three sections. Section one is from the source region to the Damodar-Barakar confluence, section two is from the Damodar-Barakar confluence to Barsul–Chanchai village where the river takes a turn towards south, and section three is from Barsul–Chanchai to the confluence of the Damodar with the Hooghly (Fig. 2.5). It is this Barsul-Chanchai section that has thrown the maximum number of distributaries in the historical past. So the debate on the definition of the Lower Damodar focuses on four important issues, as to whether or not:

i. The Khari off-take point is the beginning of the Lower Damodar if Schumm's classification is to be followed.
ii. The Mundeswari off-take point should be taken to define the Lower Damodar.
iii. The southerly stretch of the Damodar below the Barsul-Chanchai is the actual Lower Damodar.
iv. The stretch below the Damodar-Barakar confluence is the actual Lower Damodar.

The scheme proposed by P. K. Sen (1991) has been slightly modified here. The stretch below the Panchet and Maithon reservoir, the most important control structures, is defined as the Lower Damodar (Bhattacharyya 1998). The term Lower Damodar has been used for convenience while discussing the stretch between the Panchet Maithon reservoirs and the Falta point (Plate 2.1, Figs. 2.1 and 2.5). This part of the Damodar was notorious for floods; the recorded flood history dates back to 1730 (Voorduin 1947) and the last flood was in 2007. Flooding has been an issue from the dawn of civilization to the present era, despite tremendous improvements in engineering technology. Therefore, a river has been selected that still creates flood havoc despite several flood control measures for this research. Secondly, the Lower Damodar is one of the innumerable South Bengal Rivers chained by embankments, most of which predate the British Period. These embankments, constructed to control flooding, were the first control measures. Thirdly, this is the first river selected in independent India for a multipurpose River Valley Development Project, the Damodar Valley Corporation (DVC), in accordance with the Tennessee Valley Authority (TVA) model. In the studied section lie the Panchet and Maithon reservoirs, completed in 1957 and 1959. The Durgapur barrage (1958) and the Ulughata sluice, completed during 1975–1976, are other important transverse control structures. This section also contains pre-independence control structures such as the Jujuti Sluice (1881) and the Rhondia Weir (1933). There are other small control structures constructed not by the Government but by the locals, such as Rangamatia dykes at Rangamatia sandbar in the Bankura district. Fourth, the riverbed itself is extensively used for agriculture below the Maithon and Panchet reservoirs up to the Falta point. The crops, vegetables and trees grown vary from an inferior type of cucumber (*Cucumis Sativus*) and bottle gourd (*Lagenaria Siceraria*) to potatoes and mulberry plants. Finally, there are several sandbars locally known as char lands or mana that are permanently settled by Bengali refugees. Therefore, the factors behind the selection of the Lower Damodar as a specific studied section are as follows:

i. Flood propensity of the Lower Damodar
ii. Presence of a series of control structures from embankments to reservoirs
iii. Agricultural utilization of the river-bed, char lands or sandbars
iv. The presence of settlements on sandbars
v. State and community-level involvement in flood and river resource management.

2.6 Locational Reference of the Study Area

The study area from the Panchet and Maithon reservoirs to the confluence of the Damodar with the Hooghly River at Falta is a part of the Damodar drainage basin. The area extends roughly from 22°13′N to 23°40′N and from 86°46′E to 88°5′E. The total length of the Lower Damodar is approximately 250.15 km. The study area lies under the districts of Purulia, Bankura, Barddhaman (also spelled Burdwan), Hooghly, and Howrah (also spelled Haora) of West Bengal. The major portion lies within the districts of Bankura, Barddhaman, Howrah and Hooghly. Important towns near the study area are Asansol, Raniganj, Durgapur, Barddhaman and Uluberia. Kolkata, one of the four metropolitan cities of India, is not far away from the study area. The area comes under the police stations of Saltora of the Purulia district; Mejhia, Barjora, Sonamukhi, Patrasair, Indus of the Bankura district; Galsi, Khandaghosh, Barddhaman, Memari, Jamalpur of the Barddhaman district; Tarakeswar, Jangipara, Dhaniakhali and Pursurah of the Hooghly district; and Udainarayanpur, Amta, Bagnan, Uluberia and Shampur of the Howrah district. The south-eastern railway line passes through the left bank. The Grand Trunk road runs almost parallel to the railway line. Finally, the area is a part of the Rarh, the Raniganj Coalfield, the Durgapur-Asansol urban industrial complex, the industrial urban Barddhaman, and the agriculturally prosperous Barddhaman–Hooghly plains (Figs. 2.1 and 2.2).

2.6.1 Problem of Area Demarcation

The specific studied section is a part of the Damodar drainage basin mentioned above. Therefore, the selection of indicators to define the study area has posed many problems. As the study is on a controlled river, two of the control structures have been taken for demarcation. The embankments, as the primary control structures on the Damodar, demarcate the study area mostly on the left and right banks. But the problem is that the embankment does not exist beyond Silna on the left bank except for a few places upstream of the Durgapur barrage and above Paikpara on the right bank. In the absence of embankments, the natural levees, which have been protected in some places by artificial means, have been taken as the limits of the actual study area. In the absence of prominent natural levees, the riverbank has been taken as the demarcation line. Area demarcation poses a serious problem where riverine alluvial bars have almost merged with the mainland. In such a situation, a previous channel boundary has been taken as a limit of the study area (Fig. 2.6).

The western-most boundaries are the Panchet and Maithon reservoirs, the most important control structures on the Damodar. The southeastern-most limit is opposite the Falta point. Although the Damodar delta extends geomorphologically below the Falta point, the present study does not include the extended delta of the Damodar into the Bay of Bengal. Bahir Aima is the last settlement in the study area. So, following are the selected indicators to demarcate the study area:

i. Embankment,
ii. Levees,
iii. River bank,
iv. Old channel of the present Damodar,
v. Reservoirs.

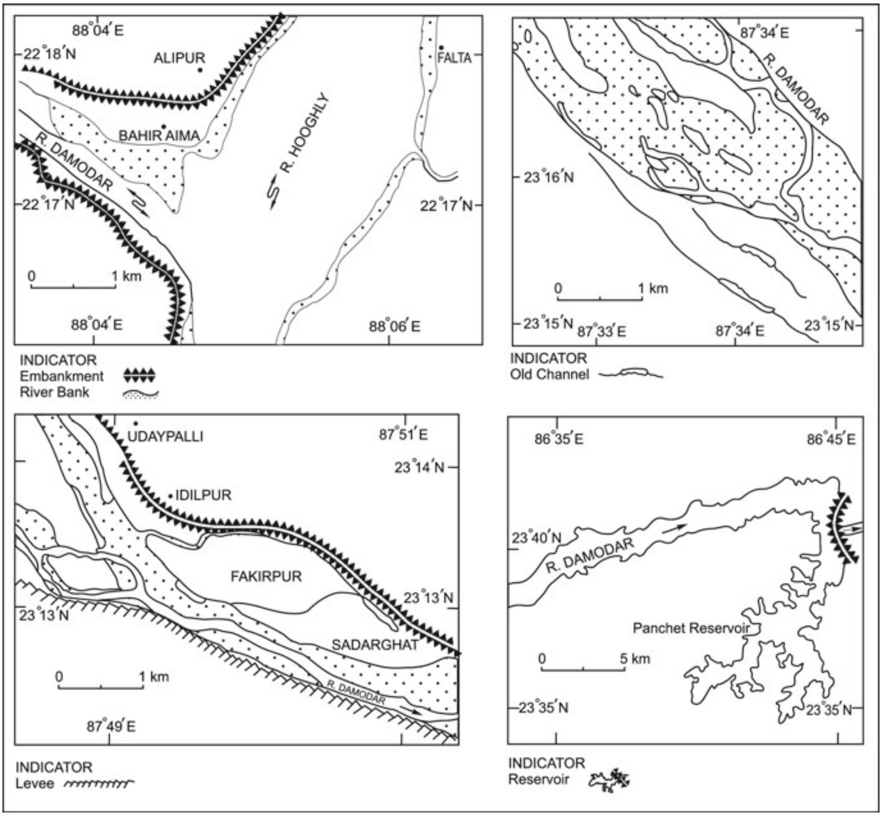

Fig. 2.6 Selected indicators for demarcating the study area

2.7 Review of Studies on the Damodar River

Although the DVC was a pioneering and ambitious project formulated after the TVA model of the USA on the eve of Indian independence, no systematic study has been done to review the post-implementation situation. There are several official papers and documents highlighting the positive impacts of the DVC in general, but no attempt has been made to assess the environmental impact of the project. The Damodar River in general has been studied by different disciplines from different perspectives. The bedrock controlled Upper Damodar and its tributaries have been geomorphologically studied by universities in West Bengal, and Bihar. Preoccupied with the Davisian model and Hortonian techniques, the studies mainly concern denudation chronology and erosion surfaces. Floods, a preferred theme as far as the Lower Damodar is concerned, are sometimes addressed directly, and sometimes from the perspective of hydro-meteorological properties of the drainage basin (Bannerjee 1943; Bose 1948).

In the pre-independence period, the Damodar Flood Enquiry Committee prepared a two-volume report in 1944, following the devastating flood of 1943. In 1950, the Bureau of Flood Control focused on flood damage and flood control activities in Asia and in the Far East including floods in the Damodar. The UN Flood Control series 16 (1960) includes an article on the Damodar Valley Corporation (DVC). Saha (1944) and Voorduin (1947) in their articles and reports have discussed in detail the characteristics of the entire Damodar Valley. There are several project reports on the DVC dating from 1950 to 2008. These reports mainly compare channel capacity, floods and flood control capacity of reservoirs, reservoir sedimentation in different years, and water resource management.

The Lower Damodar investigation committee was constituted by the DVC in 1957 to examine the possible effects of the DVC dams on the lower reaches of the Damodar River. The committee studied the pre-dam conditions of the lower reaches of the Damodar (DVC 1957a, b Vols. I and II). Bose and Sinha (1964) focused on the effects of the October flood of 1959 on the Damodar River. S. K. Sen's paper (1962) is valuable contributions to research on the Lower Damodar. He concentrates on the changing courses of the Lower Damodar. Floods, however, are mentioned only peripherally in these papers. Bhattacharyya Asit K (1973) mentions that, following the widespread flood of 1959, the West Bengal Government pressurized the DVC to adopt new water release schedule. He felt that the Damodar Valley was exposed to a greater risk of being flooded if a sudden peak flow converged on the DVC system. Satakopan (1949) concentrates on rainfall studies in connection with the unified development of the Damodar and Pramanick and Rao (1953) focus on the hydrometeorology of the Damodar catchment. Majumdar (1957) drew attention to evaporation loss in the Damodar Valley, while Chatterjee (1969) prepared a useful Planning Atlas of the Damodar Valley. Sharma (1976) analyzed the hydrologic characteristics of the Damodar River and has emphasized mean monthly and instantaneous peak discharges at Rhondia on the Damodar from 1934 to 1973 in order to study the impact of the DVC on the flow regime of the Damodar River. P. K. Sen (1976, 1978, 1979, 1985a, b, 1990, 1991, 1993) drew attention to the geomorphological analysis of drainage basins, hydrological characteristics of the Banka basin, a sub-basin of the Lower Damodar drainage basin, hydrogeomorphological attributes of the Bhagirathi-Hooghly and Damodar interfluve, recurrence of floods in the Lower Damodar basin, flood hazards, and bank erosion problems and environmental degradation. P. K. Sen (1985a) notes that the inadequate capacity of the Maithon and Panchet reservoirs necessitates huge amounts of water release during high rainfall condition, much beyond the danger level to the downstream section, inevitably causing of floods in the lower section as was experienced in 1959 and 1978. He acknowledges, however, that the flood havoc would have been much more devastating had there been no dams.

Bagchi (1977) has studied on the Damodar Valley development and its impact on the surrounding region. Datta and Dasgupta (1992) have stressed the socioeconomic significance of the DVC. Halder (1992) has made an impact study of the DVC's water management. Kumar et al. (1993) have focused on the Damodar River basin from a hazard perspective. Chakravarty (1994) has reviewed the socio-economic and environmental effects of the DVC projects in the Damodar basin, emphasizing only positive impacts of the DVC projects. He concludes that it has been amply proven that the water resource projects of the DVC have been practically an unmitigated boon to the valley. The negative effects due to the dams are practically nil or have been adequately taken care of. R. Bhattacharyya and De (1972) focus on some aspects of agriculture in the Damodar-Hooghly interfluve. Biswas and Bardhan (1975) have emphasized the agrarian crisis in the Damodar–Bhagirathi region between 1850 and 1925. There are several other short papers on other aspects of the Damodar such as nature of urbanization in the Lower Damodar (Lahiri 1986) and urban housing problems (Basu 1992).

In addition to the above-mentioned studies, this research endeavor has been enriched by the voluminous reports and records on embankments, the most important pre-British control structures on the Lower Damodar. These reports and records were prepared by engineers and British government officials. Floods and embankments have been jointly treated in the four volumes of the "Selections from the Records of the Bengal Government" which contains papers dated from the 23rd January 1852 to 18th September 1923 (Baker 1852; Dickens 1853; Ricketts 1853; Goodwyn 1854; Garstin and Mactier 1854; Voorduin 1947). During this period, Bentley (1925) discussed malaria problems and agriculture in Bengal which includes the Lower Damodar. Willcocks (1930) drew attention to the ancient system of irrigation in Bengal, including the Lower Damodar.

Looking at more recent studies, the Central Mining Research Institute (1995, 1997) used geomatics tools for studying the carrying capacity of the Damodar River Basin (DRB). The CMR Report focuses on the GIS techniques and methodologies used to design and create the geographic database and carry out analysis and modeling of the data. Chandra (2003) mentions in his short report that the DVC is acting as a River Basin Organization and is successfully implementing the concept of integrated water resources management. Self-sufficient and self-sustaining, the DVC is managing to achieve the development of irrigation, power generation, flood control and water supply facilities while taking up environmental protection measures in an integrated manner. Chaudhuri (2001, 2006) has studied the life of the Maithon reservoir, focusing on sedimentation. He observes declining storage in different zones of the reservoirs and addresses reliability of the conservational storage, rise of the reservoir bed-level, and reduction of storage trap efficiency in different projected years. Roy and Mazumdar (2005) evaluated the impacts of climate change on the water resources of the Damodar basin by using a distributed hydrological model (HEC-HMS). Chandan Ray (Ex Chief Engineer, I&W, Govt. of WB), has contributed an elaborate report (DVC 2nd Interim Report, 2008) on the flood situation in the Damodar River and its management (personal communication, dated February 15, 2009). Chatterjee et al. (2010) assessed the water quality near an industrial site of the Damodar River during the period of 2004–2007.

River control structures on the Damodar River have thus been extensively studied over the years from a variety of perspectives. One must note, however, that the issues relating to the Damodar River have not been addressed from the perspective of human interaction with the natural environment in altering fluvial environment as well as managing river resources at a micro level using non-structural approaches. From this perspective, a review of the Damodar River, a first multipurpose project modeled according to the Tennessee Valley Authority (TVA) of United States, in respect of human-environmental research is timely. The hydro-geomorphic and social changes associated with longstanding flow regulation of the Lower Damodar River have been addressed in this study. Moreover, a significant focus has been placed on human effort in managing flood and water resources and the reciprocal relationship between human modification of the river and the human adaptation to changing hydro-geomorphic adjustments within the riverine char lands.

2.8 Conceptual Background

Concepts help in inter-disciplinary communication and in explaining empirical phenomena. Concepts enable researchers to generalize and formulate theories. In absence of an a priori model to examine human-environment interactions and applied geomorphological issues in a controlled riverbed, several concepts from inter-connected disciplines will be considered to verify empirical facts. The concept that forms the basis of this research is the concept of a controlled river. The issues here are applied geomorphological issues; therefore, the concepts of applied geomorphology and literature on the subject need to be reviewed and elaborated. To clarify geographic or spatial perspective, the concept of geomorphic space with applied connotations will be discussed.

One of the objectives of this research is to explain human interaction through land use on the riverbed of the Lower Damodar. Therefore, a brief discussion of the concepts of land, land resources and land use is necessary. Some concepts such as social space, perception, culture, refugee, human ecology and hazard, borrowed from sociology, anthropology and ecology, have been considered in explaining land use characteristics and human adaptation with changing riverine regimes. Applied geomorphology is indebted to philosophy also; empiricism, possibilism and probabilism are philosophical concepts which enable a researcher to organize thought in a meaningful way.

2.8.1 Controlled River

Rivers from the dawn of civilization have become functional entities and have been trained to serve one or more purposes. Control measures range from deepening, widening or straightening of a channel, drainage diversion, chaining a river with embankments to impounding a river through weirs, barrages, and reservoirs. A river is referred to as a controlled river when its discharge, sedimentation process and other channel behaviors are controlled by engineering structures. Sometimes one of the parameters is purposefully controlled by a single structure; sometimes several parameters are controlled by multitudes of structures in phases. But the parameters are so inter-linked that a measure taken to control one aspect may bring sequential changes to other aspects as well. Controlling a river is an anthropogenic intervention in the natural river system.

2.8.2 Geomorphic Space and Landscape

In geography the term “space” refers to the space of the physical world and geometry is a language in which it is described. Space, in fact, is a container of all geographic phenomena which are not necessarily just physical phenomena. Broadly speaking, geographic phenomena include non-physical phenomena such as agricultural fields, factories, settlements, and transport lines. Geomorphological space is referred to in the present study as a space which contains landforms, land forming materials and land forming processes. In traditional geomorphology landforms are natural features such as mountains, plateaus, and basins. Land forming processes are fluvial, aeolian, marine processes etc., and land forming materials are either inherited materials from below or acquired materials produced by exogenetic processes. But in applied geomorphology, anthropogenic process is acknowledged as a viable geomorphic process. The artifacts or cultural features come into existence due to human intervention with the natural system. Thus settlements, agricultural fields, cultivated vegetation, and roads and railways, become essential components of space. An artificial levee or an embankment, an artificial water body such as a weir or reservoir, or artificial channels such as canals, diversion channels, and drainage ditches become inseparable ingredients of the inherited physical space. Verstappen (1977, 1983) has stated that in applied geomorphological research cultural features are effective indicators of physical space modified by anthropogenic processes. Therefore, a geomorphic space not only contains landforms produced by endogenic and exogenetic processes and materials produced by these processes, but also cultural features that have emerged through anthropogenic processes. The cultural features are designated as human made landforms or anthropogenic landforms (Brown 1970; Golomb and Eder 1971; Goudie 1989, 1990; Bhattacharyya 1998). Therefore, an applied geomorphologist has to consider the geographic space from two angles; (i) inherited physical space and (ii) physical space modified by anthropogenic intervention. Similarly, to an applied geomorphologist, the term “landscape” is dynamic and heterogeneous through both space and time (Gillson 2009) and not only includes natural landforms such as mountains and rivers but is also shaped by long-term human land use (Kondolf et al. 2007) that includes settlements, agricultural fields and many other artifacts. A space thus produced is the geomorphic space.

2.8.3 Geomorphic Environment

“Environment” is a term that has been widely used since 1970. Environmental geomorphology is now an accepted sub-discipline of geomorphology. Expressions such as environmentalism, hazard, environmental degradation and environmental perception are also common in geographical literature. Although the term “environment” is commonly used, it is a problematic term that lacks a proper objective definition. Most books define environment as a natural and cultural setting within which people live. Environment, so defined, embraces the physical, chemical and biological environment and includes social, political, economic, and technological dimensions. Physical scientists are mostly interested in the non-human natural environment whereas social and applied sciences focus on the cultural environment (White et al. 1984). Although applied geomorphology and human-environmental research are applied sciences, the present study uses the term “geomorphic environment” in both the physical and cultural sense. In applied geomorphology, anthropogenic processes, materials and forms have strong significance. Therefore, the geomorphic environment, like geomorphic space, consists of natural features, modified natural features as well as artifacts.

2.8.4 Empiricism

Empiricism asserts that all knowledge is derived from sense-experience. The empiricist philosophers, both Indian and Western, are unanimous on this basic conception of empiricism. Locke, Berkeley and Hume are traditional empiricist philosophers in Western philosophy. In the Indian tradition, the Carvacas are generally recognized as empiricists, but the Nyaya-Vaisesika philosophers may also be considered empiricist philosophers in the true sense of the term. The Carvaca philosophers accept perception as the only right source of knowledge and this perception solely depends on sense data (Varodaraja 1903). In the West, the empiricist philosophers admit two types of experience, outer perception and introspection. By the former, we know the external world, and by the latter, our own mental states and processes. Locke says that the external world produces impressions on the mind and these impressions, along with the internal perceptions, are all the materials of knowledge. Locke compares the mind to a dark chamber with only two windows, viz., perception and reflection (introspection) which are the only means of communication with reality. Hume holds that all knowledge comes from impressions and ideas. Ideas are faint copies of impressions. We sometimes infer from past and present experiences but inferences are true only for actual experience and not outside it (Hume 1982).

In India, the Carvacas considered perception to be the only source of valid knowledge. According to them, what is arrived at by means of direct perception is the only truth. What is not directly perceivable is non-existent. They recognize the facts of experience alone and not those known through the process of inference (Radhakrishnan 1956). The Nyaya-Vaisesika philosophers also admit inference, analogy and verbal testimony as right sources of knowledge, but they consider perception to be the primary source of knowledge on which all other sources of knowledge depend. So according to them, perception is of a stronger authority than inference, analogy and verbal testimony (Varodaraja 1903).

2.8.5 Environmental Determinism and Possibilism

Environmental determinism is a philosophical concept which is both a feature of geography's past and a persistent theme in its present (Gold 1980; Gregory 1986). As an idea in vogue during the first third of the twentieth century, it gave primary importance to the influence of physical environment on human activity (Dutt et al. 2010). The basic idea is that human behavior can be predicted by referring to the attributes of the physical environment with which participants have to interact. This cause and effect doctrine is also referred to as "Environmentalism". Ratzel (1899), Semple (1911) and Huntington (1907, 1915) are the ardent supporters of this doctrine, but Vidal de la Blache (1921) along with Bowman (1934), Spate and Learmonth (1967) and Dutt et al. (2010) proposed a nondeterministic doctrine. They argued that within a given geographical setting there are several choices that humans can make about their activities (Kolars and Nystuen 1974; Dutt et al. 2010). In their view, it seems, human beings and not nature had the upperhand (Spate and Learmonth 1967; Dutt et al. 2010). These two doctrines will be examined in explaining land use characteristics.

2.8.6 Culture

Communities perceive geomorphological resources and hazards through specific cultural lenses. Human use of forms, processes and materials is conditioned by culture. Applied geomorphologists and anthropologists have noted the role of culture in identifying and reviewing applied geomorphological and human environmental issues. Definitions of culture are numerous. Kroeber and Kluckhohn (1952) listed over 160 different formal delimitations of the term. One of the best definitions is given by E. B. Tylor (1874) who describes cultures as "the complex whole which includes knowledge, belief, art, morals, law, custom and any other capabilities and habits acquired by man as a member of society." Culture includes all the elements in the natural endowment of human beings that he or she has acquired from their group through conscious learning by a conditioning process. It is universal human experience, yet each local or regional manifestation of it is unique. Culture is stable yet subject to continuous and constant changes, filling in and largely determining the course of our life (Tylor 1874; Herskovits 1974, p. 305). It is also extremely important in appraising spatial organization. It results from interaction between people sharing a specific area (Fielding 1974). Geographers have borrowed this concept of culture from sociology and anthropology and have introduced the term "cultural landscape". Cultural landscape is a landscape which emerges from the interaction of human communities with the environment (Bhattacharyya 1998). Culture helps in shaping cultural landscapes through environmental perception (Singh 1994). Sauer (1925) notes that cultural landscape must be interpreted as resulting from cultural processes operating over a long period of time. It is Clayton (1971) who first realized the importance of culture in geomorphological investigation. Verstappen (1977, 1983) noted that cultural features such as roads and settlements can be taken as viable indicators to analyze a dynamic geomorphic surface. Therefore, in the present study, the concepts of both culture and cultural landscape have been used.

2.8.7 Perception

The term perception has been used while elaborating the concept of social space. This term needs an explanation since the perception survey technique has been utilized in the present study. Perception refers to the response of the senses to external stimuli on the one hand and purposeful activity in which certain phenomena are registered distinctively and blocked out on the other. In western philosophy, the concept of perception has been considered together with the concept of empiricism. In the field of applied geomorphology, Craik (1970) and Clayton (1971) have already pointed out the importance of the concept of perception. Cooke and Doornkamp (1974) have acknowledged Craik and reiterated that human response to environment depends on how a human interprets the environment rather than what it is actually like. A person acquires an environmental perception while inhabiting a space (Singh 1994). Hart in his book "Geomorphology, Pure and Applied" (1991), has quoted Craik in the chapter on "Modern Applied Geomorphology." Ward (1973) states that "perception is the cognizance of the real world environment as it has been assessed by an individual. This includes the physical, social and economic complexities of past, present and future events and their meanings as they relate to the decision making processes" (Kolars and Nystuen 1974, p. 378).

Perception in the geographical sense is something more than a stimulus to a chain of memories which are conditioned by targets and objectives, decisions, actions and previous experience. Perception is conditioned by factors such as culture, sex, level of education, upbringing, position in the family, position in the neighborhood, duration of stay and attitude towards the environment. There is a cognizable difference in the evaluation of the same environment by explorers and colonists and locals of disparate background and experience. The concept of perception and relevance of perception are to be found in the studies of Saarinen (1966), Burton and Kates (1964), Burton et al. (1978), White (1945, 1961, 1974, 1994), and Gregory (2006) particularly in drought and flood-related studies. Brookfield (1969) places perception in the methodology of cultural and historical geography; but perception as a concept can unify several strands of geography, be it human geography or geomorphology. He distinguishes between "environmental perception" and "perceived environment." The perceived environment is taken to mean the whole "monistic surface" on which decision is based, including natural and non-natural, visible and non-visible, geographical, political, economic and sociological elements. Environmental perception, on the other hand, is the perception either of the whole environment, or of specific selected elements within it, or even of "space" in the abstract. Essentially environmental perception is a property of the mind rather than a construct of that mind (Bhattacharyya 1998). However, the perception of human role in changing fluvial regime varies with space and over time. How well the dynamics of the catchment hydro-system are appreciated and enlightened the perception by individuals may affect all forms of local decision-making (Downs and Gregory 2004). In the present study both the concepts of perceived environment and environmental perception have been considered while discussing human role in changing the controlled Damodar River.

2.8.8 Social Space

Applied geomorphologists and ecologists have acknowledged socio-cultural and/or socio-economic factors in explaining geomorphological phenomena. Craik (1970) is in favor of the concept of perception in applied research, a fact that has been mentioned earlier. Social space is a perceptive space disparate from "geomorphic space". The concept of social space was first introduced in 1890 by E Durkheim, one of the father figures in sociology. Durkheim defines social space as a person's position in a sociological space and not his situation in physical space. Sorokin (1928, 1959) used the term "social space" to denote an individual's relation to other people or to other social phenomena. Sorokin's social space was thus defined as a system of coordinates whose horizontal axis referred to group participations and whose vertical axis referred to status and roles within this group. Chombart de Lauwe (1952, 1956), a geographer, states that social space is a framework within which subjective evaluations and motivation can be related to overtly expressed behavior and the external characteristics of the environment (Buttimer 1980). He identifies two distinct components in social space: firstly, an objective social space where social structure and organization or groups are conditioned by ecological and cultural factors and secondly a subjective social space i.e. space as perceived by members of a particular group (Buttimer 1969, 1980). Sorre (1957) relied a great deal on the work of Durkheim and was impressed by the Chicago School of Human Ecology. He liked to integrate the subjective and objective dimensions in the development of social space. Buttimer (1969) defines social space as a mosaic of areas each homogenous in terms of space perception of its inhabitants. According to Theodorson and Theodorson (1969), a social space is a perceived space.

Reviewing the definitions of social space given by geographers and non-geographers we may say that social space has a subjective connotation and differs from physical or material space or geomorphic space. One's response to material space or components of material space or geomorphic space is colored by one's position in society. In resource utilization or in developing a functional relation with an inherited resource base, one's position in society or one's perception of social environment plays a decisive role (Bhattacharyya 1997, 1998, 2009). Even settlement sites are selected on the basis of social space. In the face of a hazard, physical parameters of an event are important, but more important are who you are and what your position is in society. Therefore, the concept of social space will be examined in the present study.

2.8.9 Land, Land Resources and Land Use

Land is commonly defined as a kind of property and persons possessing enough land are treated as landed gentry. Land can be considered a commodity as it has both use value and exchange value as well. In the pre-agricultural period, when population density was very low and ample land was available, “land” used to be labeled as a “free good”. In geography “land” implies the earth’s surface in its totality including the parcel of atmosphere resting on it. In geomorphology, “land” is used in unison with “form” in the term “landforms”. A combination of landforms is a “landscape”. When landforms and their attributes are casually linked with each other then the conglomerate of landforms is considered a “land system”. In resource geography, land is regarded as a resource base rather than a resource itself (Mather 1986). In resource economics, land is a fund resource unlike flow resources such as air and water. Land is a non-renewable resource when part of the land is totally consumed as in the case of mining. Erosion processes also truncate this resource. Large tracts of land are lost due to riverbank erosion or coastal erosion. Land is a renewable resource if its forms and materials, particularly materials, are used year after year as in agriculture. But if fertility is impaired due to faulty agricultural practices then land is treated as a non-renewable resource. Is land a limited resource? It is true that earth’s land surface is limited, but land can be put to multiple uses. It is thus difficult to place land into the conventional classification of resources. What is noteworthy is that land becomes a resource because of its functional relations with its occupiers and users and this functional relation is reflected in land use (Bhattacharyya 1998, 2009).

Land use is a permanent or cyclic intervention in order to satisfy different types of human need. Land use is nothing but the application of human control on land in a systemic manner (Vink 1975). In land use, people use the land to promote or foster the useful components and remove unwanted elements to maximize or optimize the land’s potentialities. Economics is an important factor in land use and is a major influence in competition between potential land users. Here the concept of economic rent i.e., the net value of the returns arising from the use of land in a given period of time is very important (Found 1971; Mather 1986).

The concept of land use is an admissible concept in applied geomorphological research. F. Dixey, in 1962, when applied geomorphology was in a nascent stage, appreciated the importance of geomorphological knowledge in the matter of land use: “It is necessary to know something of the origin and nature of the landforms considered, both in respect of their geological history and their topographic expression and to know also to what extent they can be regarded as stable or transient, and the trend of any changes that may be taking place” (Dixey 1962, p. 6). This concept of land is important when a piece of land is put to specific uses. Verstappen states with conviction that there is a distinct relationship between geomorphological situation and land utilization in rural areas, but at the same time he admits “the cultural and socio-economic conditions may modify or in technologically advanced areas, obliterate to some extent the effects of physical environment, but they are seldom completely antagonistic to natural patterns”

(Verstappen 1983, p. 111). Cooke and Doornkamp (1990) cite an example from the desert plains in South America where irrigation and agriculture are hampered due to lack of knowledge of geomorphology of that area. Brunsden (1981) is of the opinion that geomorphologists are capable of providing supplementary knowledge on land use, land and land quality etc. Hail (1977) and Goudie (1989), also acknowledge admission of land use in applied geomorphological studies. Thomas (1956), Brown (1970), Hails (1977), and Ritchie (1981) proclaim that human beings shape the earth and this shaping of earth takes place through the land utilization process. In South Asia, the concept of land use is considered if there is a strong correspondence between relief and land utilization. As the applied geomorphological perspective has yet to gain a footing in geomorphology, the concept of land use is applied sparingly by researchers. In the present study, one of the objectives is to examine the land use characteristics of the controlled riverbed. Therefore, the concepts of land, land resources, and land use have been elaborated above.

2.8.10 Hazard

The 1990s were declared the International Decade for Natural Disaster Reduction (IDNDR). Hazard or disaster or calamity may be defined as an occurrence causing damage, loss of human life and property, deterioration of health and other essential economic services on a scale that demands an extraordinary intervention from outside the affected community. Contemporary thinking recognizes that most hazards are usually hybrid, classified into two groups, natural and human-made (Faulkner and Ball 2007). There is a third category which is referred to as quasi-natural. Some geophysical events such as earthquakes, floods, droughts and tropical cyclones are natural hazards. The Chernobyl accident of the former USSR in April 1986 and the 1984 Bhopal gas disaster in India can be referred to as human-made or anthropogenic disasters. However, floods due to breaching of embankments or collapse of dams are not totally anthropogenic, as flooding is a process governed by physical laws. Similarly, the cause of soil erosion due to deforestation may be anthropogenic, but soil erosion is a natural process. These are examples of quasi-natural hazards i.e. they are neither natural nor purely anthropogenic. White (1974) has discussed in detail the concepts, methods and policy implications of natural hazards; in the previous articles (1945, 1961) focused on floods, and more recently (1994), he deals with natural hazard in a broader perspective. Bhattacharyya (1991, 1998, 1999) has discussed in detail the concept that floods, once the basis for hydraulic civilizations, might be translated into social disaster due to negative interaction between human use system and environmental conditions at a particular historical juncture within specific economic and social conditions. Burton et al. (1978) examine how communities respond to so called extreme events in nature. They emphasize natural event systems vs. human use systems in a disaster study and raise a pertinent question regarding whether our environment is becoming more hazardous. Kates (1962) is another significant contributor to hazard research. His theme ranges from hazards and choice perception in floodplain management to natural hazards in human ecological perspectives (Kates 1971, 1994). Hewitt's (1983) book contains several articles on calamity from different perspectives. Bryant (1991) may also be included in the same category.

Other contributors to the literature include Saarinen (1966) who focuses on perception in assessment of hazard, as well as Chen (1973), Scheidegger (1975), Butler (1976), Hewapathirane (1977), Heathcote (1979), Whittaw (1980), Hodgkinson and Stewart (1991), Mc Call (1992), Blong (1992), Brook (1992), Blaikie et al. (1994), Mileti (1994), Mustafa and Wescoat (1997) and Mustafa (1998, 2005). While dealing with floods, they never mention that a flood is a geomorphological or hydro-geomorphological process. They treat a flood as a natural event which causes a disaster. It may be said that they have treated floods from an environmental perspective. Dynes (1970) has treated disaster entirely from a sociological perspective and Quarantelli's (1978) perspective is economic, but they agree that floods and other geo-physical events have a negative connotation. In some of the articles, the negative connotation of natural events has been challenged.

There are three distinct schools in hazard research. One school believes that a disaster situation depends on the physical parameters of the event, such as frequency, magnitude, speed of onset, duration, length of possible forewarnings, predictability and controllability. Burton, White, and Kates belong to this school. The second school believes that the severity of a natural hazard depends upon who you are and to what society you belong at the time of disaster. This school further states that humans do not enter into a set of contracts with nature. They have to interact with each other for fulfillment of their basic needs and the intrinsic quality of this interaction determines how individuals or groups relate to nature. Therefore, it is meaningless to separate nature from society. Response patterns in the face of calamity depend upon the position of people in the society and in the production process. This school, to which Susman et al. (1983) belong, is guided by the Marxist philosophy. A third school uses the term "hazardscape" in their discussion of large dams. This arises from ideas in hazard research, political ecology and the social nature tradition (Mustafa 2005).

Verstappen (1983) is the pioneer geomorphologist who included natural hazard and the significance of natural hazard in applied studies. Pitty (1982) is another noted geomorphologist who understood the relevance of natural hazard in geomorphological study. Pitty has also used the term man-made hazard research. Gares et al. (1994) have linked natural hazard with geomorphology. Rosenfeld (1994) clarifies the role of geomorphology in hazard research. Finally, Cavallin et al. (1994) focus on the role of geomorphology in environmental impact assessment. Climate change and development pressure on flood plains has made people more vulnerable to flood hazards. The collection of articles in the book "Flood Risk Management in Europe: Innovation in Policy and Practice" (Begum et al. 2007) deals with various issues related to flood risk management, flood impacts, flood analysis, and flood forecasting. In the present study, hazards or disasters have been treated from an applied geomorphological perspective. For example, flood borne materials and flood built features can either be seen as part of the resource base or, under changed circumstances, concomitants of disaster (Bhattacharyya 1998).

2.8.11 Human Ecology

Applied geomorphologists generally do not use the term human ecology. Many articles with applied geomorphological connotation, however, are to be found in books on human ecology with examples of human survival under environmental changes and in face of environmental adversities. Human ecology concepts are relevant to the present study to the extent that this research deals with the adaptation of riverbed settlers to their changing fluvial environment (Bhattacharyya 1997, 1998). The term "human ecology" was first used or introduced by Park and Burgess in 1921 (Theodorson 1961). They attempted to apply the basic theoretical scheme of plant and animal ecology to the study of human communities. Long ago in 1922, H.H. Barrows used this term human ecology in his presidential address to the Association of American Geographers (Eyre and Jones 1966). There are several definitions of human ecology. RD Mckenzie conceived of human ecology as "a study of the spatial and temporal relation of human beings as affected by the selective distributive and accommodative forces of the environment." The basic human ecological idea is the concept of competition. This competition among human beings involves struggle for position i.e., struggle for a niche in which individuals may survive and function. The typical arrangement of human communities is conceived to be a function of competition (Mckenzie 1968, pp. 40–41). Sergent II (1974) states that human ecology seeks to understand man and his problems by studying individuals and populations as biological entities profoundly modified by culture and by studying the effects of environment upon man and those of man upon his environment. There are three possible human environment relationships. First, human is reducible to environment. Second, environment is reducible to human. The third relationship is the one in which two interdependent systems, human and environment, reciprocally interact. Human ecologists believe in the third approach, i.e. one in which human beings live in symbiotic relations by means of division of labor and this division of labor is based on cultural and geographical dissimilarities. Human symbiosis represents a wide range of sustenance. The form of this symbiotic relationship between different ethnic groups differs with changing environmental circumstances.

Dansereau (1957) has classified human interference on a six-point scale, each representing a stage of cultural evolution. These stages are gathering, fishing, herding, agriculture, industry and urbanization. Symbiotic relation changes with the changes in the stage of cultural evolution. In a nutshell, human ecology studies the human struggle for existence. The concept of the survival of the fittest was first proposed by Darwin (1859) and Park (1961) and was later borrowed by human ecologists. Darwin's concept is very popular in capitalist countries. They believe that, in the struggle for existence, the fittest ones will survive in the natural selection process and that this fitness is genetically transmitted. This concept is labeled a bourgeois concept by the Marxist philosophers. It is sometimes slightly modified to assert that fitness can be culturally acquired. In books on human ecology there are examples of how man has survived against environmental adversities or under environmental changes. For example, in the book entitled "Studies in Human Ecology" edited by George A. Theodorson, there is an article that describes how the settlement Vicksberg was detached from the main flow of the Mississippi due to a neck cut-off in the 1876 flood and how it survived thereafter due to a judicious construction of a diversion channel in 1914 from the River Yazoo, a tributary of the Mississippi (Preston 1961).

The effects of reservoirs in Africa have been described by Obeng (1976) in his article “Man-Made Lakes and Problems of Human Settlement in Africa” published in “Human Ecology and the Development of Settlements” edited by J. Owen Jones. In Africa the Lake Kariba on the Zambesi, the Lake Nasser on the Nile, the Lake Kainji on the Niger and the Lake Volta on the Volta River show some negative impacts such as increased seismic activities, excessive deposition of sediments and silts, destruction of habitat for fish, aggravation of public health problems, displacement of population and readjustment problems of displaced persons. Obeng believes that these adverse effects can be minimized. Similarly, the Hoover dam on the Colorado was discussed in terms of discharge and sediments in a article entitled “The Head of the Colorado Delta” written by Homer Aschmann, and published in “Geography as Human Ecology” edited by S. R. Eyre and G. R. J. Jones (1966). Therefore, in the present investigation, the concept of human ecology has been used together with the concept of social space since both these concepts are interrelated. One’s struggle for existence or search for a niche or identification of geomorphic forms, processes, and materials as potential resources are, to a great extent, conditioned by one’s position in society. Under similar physical environments, the nature of one’s struggle varies according to one’s position in the social space or perception of social environment (Bhattacharyya 1997, 1998).

Burton and Hewitt’s (1974) article on hazard suggested a range of theoretical adjustments to selected environmental events. One such event mentioned in the article is flood. They have observed four types of adjustment in the face of floods; modify natural events, modify the human use, emergency adjustment and adjustment to losses. Non-structural adjustments to mitigate flood distress in flood prone areas include flood plain zoning, flood proofing, land use planning, and working to prevent and prepare for floods (Bhattacharyya 1998, 2011).

2.8.12 Refugee

“The concept of refugee is at once a legal, political, cultural and sociological category” (Kuper and Kuper 1995, p. 726). The technical meaning of the term “refugee” was developed between the two world wars. The concept was elaborated in the refugee convention of 1933. The 1951 “UN Convention Relating to the Status of Refugees” emerged as a result of the European experience of the Second World War. Refugees, according to International Law, are defined as “aliens” in the state to which they migrate to settle down. The term “refugee” is popularly defined as a person fleeing from war and civil strife. Researchers and International agencies usually define a refugee as one outside his or her country (Hugo 1987). Refugees may be typed as majority–identified (political refugees), events–alienated and self-alienated refugees according to their willingness to return to their motherland (Kuper and Kuper 1987). The Government of West Bengal defines a refugee as a person who was displaced from an area outside India on account of civil disturbance or fear of such disturbances. A refugee is a person who has lost wholly or partially his business, industry, or property outside India on account of civil disturbances. The defect of this definition is that while defining refugee, a person is defined and not a family. A refugee in a true sense speaks different language and usually belongs to a different religion. In the present study, the term refugee has been used for the person who migrated to India after 1947. In West Bengal the refugees speak Bengali and are mostly Hindus and so may not meet the technical requirement for a refugee to speak a different language or belong to a different religion. Here "evacuee" is a better term, but in the present investigation the widely accepted term "refugee" has been used instead of the term "evacuee".

The concept of "refugee" is neither a geomorphological nor an applied geomorphological one. Applied geomorphological issues have been dealt with at two levels. Level one includes professional planners and engineers who use geomorphological knowledge to solve socio-economical problems at the national and regional levels. Level two includes mostly locals and migrant communities who use geomorphological knowledge for resource identification, resource utilization and hazard reduction (Bhattacharyya 1997, 1998, 2009). The migrant community in the studied area consists mostly of Bangladeshi migrants or Bangladeshi refugees. Therefore, the concept of "refugee" has been discussed.

2.9 Objectives

The objectives of the present study are as follows: review state and community level initiatives in flood and water resources management; assess the impacts of river control measures on selected hydro-geomorphological parameters of a tropical alluvial river in its low gradient sector; and review the socio-economic significance of such control measures and consequent anthropogenic changes in the fluvial environment.

The river that has been selected is the Lower Damodar which was once notorious for the flood havoc it caused in undivided Bengal. Embankments were the first control structures to tame this river. Therefore, it is imperative to trace: (i) the flood characteristics and flood history of the Lower Damodar, (ii) the phases of control measures in the said section chronologically and chorologically, (iii) the consequent changes in discharge, sedimentation and channel characteristics.

Such changes, it is admitted, are of great hydro-geomorphic significance. The objective, however, is to focus on them from both the resource and hazard perspectives. This may need further clarification.

Throughout tropical Asia, the pressure of population has forced socially and economically marginalized sectors of the society to occupy flood-sensitive tracts. Riverbeds, the most vulnerable tracts, are put to extensive and intensive agricultural use known as "river-retreat"[2] land use particularly where rivers are highly seasonal and channel deposits consist of finer materials (Bhattacharyya 1998). So almost everywhere in tropical Asia, farmers explore the exposed fine-grained channel deposits by lowering the flood level and decreasing discharge. This is the scenario in the Indian subcontinent, particularly in India and Bangladesh. Migration, exposure, and submergence of channel deposits become sensitive socio-economic and political issues near the district-state and international boundaries. These issues have also been discussed in the present study, although tangentially. What is important to note is that, in the study area, channel deposits are not only agriculturally used, but most of the channel bars have settlements and the settlers are mostly Bangladeshi refugees. Therefore, the channel deposits and channel discharge in the study are socio-economically significant. Therefore, the objectives in this context are to trace: (i) the socio-economic and socio-political history of colonization in the riverbed, (ii) the impact of control measures and consequent changes on the perception of the riverbed occupiers, (iii) the history and characteristics of land use in the riverbed.

In brief, the goals of the present study are to review the flood characteristics and flood history of the Damodar River, flood control measures and their impact on fluvial regimes, history of colonization in the riverbed, and land use characteristics along with emergent landscape in the channel bars. In other words, this research reviews the impacts of control structures in the downstream environment and also makes an attempt to understand anthropogenic changes to the river regime by describing the way in which people, ranging from refugees to local settlers, driven by diverse cultural, economic, religious, and political forces, have transformed the fluvial landscape and are living with floods and dams.

The following implicit questions have also been addressed as part of the present study: (i) Do excessive river control measures serve the expected socio-economic purposes? (ii) Should we encourage indiscriminate use of a riverbed? (iii) Does a channel deteriorate due to rapid anthropogenic stabilization of the channel bars? These questions have significance at the national and international levels and can demand, justifiably, some research endeavor for a reasoned answer. They form a corollary to the primary objectives.

2.10 Research Paradigm

There has been a marked paradigm shift in geomorphology from structural to applied and environmental. Prior to the mid 1880's, geomorphology was an amorphous concept and the term was yet to be coined. In that period Hutton, Playfair, Smith, Lyell, Agusses, Powell and Gilbert contributed to the concept. In 1889, Davis proposed the historical concept of landform evolution and the Davisian school ruled the discipline of geomorphology until 1960. In this landmark year for geography, LD Stamp first used the term "applied geography" (Frazier 1982). In 1962 Chorley

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[2] Water level lowering riverbed use for quick growing vegetables.

introduced the concept of systems theory and Kuhn used the term “paradigm” (Chorley 1962; Kuhn 1962). Way back in 1954, though, Thornbury introduced the term “applied geomorphology” and devoted a separate chapter to the topic in his book. He also gave a precise definition of the term by stating that “applied geomorphology” is the application of geomorphic knowledge in planning and management (Thornbury 1954). It is Cooke and Droonkamp (1974, 1990), however, who are treated as father figures in applied geomorphology. They roughly defined “applied geomorphology” as a deliberate attempt to concentrate on geomorphological expertise in the solution of practical problems. The thesis that man is a geological agent in shaping the earth was proclaimed by Sherlock (1922) who realized that human beings play a role in actions such as disturbing the flow of underground water or changing the course of a river. Direct consequences of human activities are also supported by Thomas (1956), Wolman (1967), Brown (1970), Golomb and Eder (1971), Gregory (2006), James and Marcus (2006), Kondolf et al. (2007), Bhattacharyya (1998, 1999, 2002, 2009). In 1960, L. D. Stamp introduced the term “Applied Geography” (Frazier 1982). This was probably the year that spelled the end of the concept of erosion cycle and denudation chronology (Hart 1991). Stamp (1960) also defined “Applied Geography” as an application of geographic knowledge and methods to solving economic and social problems. Thus, practical problems, either economic or social or both, are focused on in Applied Geography and Applied Geomorphology. Both disciplines take a welfare approach. From 1970 onwards applied studies multiplied noticeably. 1980 is the beginning of human-environmental studies and “applied geomorphology” took on a new form as “environmental geomorphology”. In different parts of the world the earth system components are now more controlled by anthropogenic forces than by natural forces (Turner et al. 1990; Messerli et al. 2000; Meybeck 2003), showing a marked paradigm shift that has led to the current era being termed the “Anthropocene era” (Crutzen and Stoermer 2000). But way back in 1864 Marsh forewarned that irrational treatment of the environment by human beings might destroy the very base of subsistence of human society. Vernadski (1926) also coined this concept at a period when human-environmental interaction was very limited (Meybeck 2003).

During the past few decades “Environmental Impact Assessment” (EIA) has been adopted in many countries in order to assess and mitigate the environmental effects of large-scale engineering projects such as electrical power plants, chemical works, railways, and river valley projects on riparian ecosystems (Braatne et al. 2008). Among these effects, the natural component must be examined in terms of geomorphological hazards which may endanger a project or other geomorphological assets (Cavallin et al. 1994). Current research on human impacts and changing natural environment reviews linkages of human land use, structures, and channel modification with geomorphology, hydrology and ecology (James and Marcus 2006).

The structural geomorphological perspective is still popular in geomorphological research where there are noticeable structural variations at regional scale and lithological variations at local scale. There are practically no structural variations in the Damodar River. Lithological variations are also negligible and there is no correspondence between landforms and structures and lithology. For example, the exposure of the Gondwana sandstone and shale in the Raniganj coalfield west of Durgapur and newer alluvium in the east does not make any relief variation (Fig. 2.1). Therefore, this structural perspective or approach has no significance in this research.

Application of Davis' historical or diachronic perspective is still very common among Indian geomorphologists. The Davisian perspective, however, has lost much of its significance since it deals with a physical environment which does not include humans or anthropogenic processes. This study begins with controlled structures which are anthropogenic landforms in a historical environment. Also, application of the Davisian approach requires an extensive spatial scale and extended time horizon. In this research, the study area is small and spans a time frame less than 500 years compared to the Davisian time scale of about 15 million years.

Chorley and Kennedy's systems approach (1971) is gaining popularity all over the world particularly in the assessment of hydro-geomorphological consequences of reservoirs, but they too have certain limitations. They have not touched upon social aspects in geomorphological investigation. Secondly, Chorley's systems approach requires a large set of quantified data and analysis of complex relationships between different phenomena in a system. Due to paucity of complete data, it was not possible to apply Chorley's systems approach even though it is of paramount significance in modern geomorphological research.

Considering all these factors, we have adhered to the applied geomorphological approach defined by Thornbury (1954) and later modified by Coates (1971, 1972–1974), Cooke and Doornkamp (1974, 1990) i.e., geomorphological information can be applied to solve practical problems arising out of geomorphological or hydro-geomorphological phenomena such as floods and geomorphological expertise can be used for geomorphological hazard and resource identification as well as for hazard reduction and resource utilization (Bhattacharyya 1998).

The applied perspective in the present study has two levels. At the first level geomorphological knowledge is utilized for constructing control structures on the Damodar. Engineers, hydrologists, geomorphologists and planners have used their knowledge at national and regional levels. The embankments, sluices, weirs, barrages, and reservoirs are outcomes of planning at this level. At the second level it is the riparian communities who use geomorphological knowledge (though they are not aware of the term geomorphology) to identify and explore resources for sustenance in the bed of a controlled river. They are shaping their fluvial landscape through environmental perception while inhabiting a river space.

2.11 Applied Geomorphological and Human-Environment Issues

Applied geomorphological and human-environment issues are location-specific, time-specific and culture-specific as well. Soil erosion may be a problem in one area. Excessive sedimentation in the riverbed may create problems somewhere else. Avulsion may be a problem in one region; neck cut-off may create problems in another. Landslides may pose serious problems in some areas whereas collapse of the river bank may be a hazard somewhere else. Thus, these issues vary from place to place. There are temporal variations in applied issues as well. Bank erosion may be a problem now; excessive riverbed sedimentation may pose problems in the future. The issues are also culture-specific. Flooding and creation of waterlogged bodies may be a menace to cultivators but a welcome occurrence to fishing folk (Bhattacharyya 1998).

Significance of applied issues also varies according to local, regional, national and international levels. Rising sea levels and consequent flooding of coastal areas in certain parts of the tropics due to climate change are international issues. Sharing of river water between adjacent countries and related problems has great significance at national and international levels, but shifting bank lines and bank erosion in a particular area affect the locals more. Taking all these factors into consideration, issues are selected that may appear to be only of local significance, but ultimately have regional and national implications, too. These issues are often of consequence even at the international level.

2.12 Models and Methods

There are no specific models which can be duplicated in the present study. Although the DVC was formulated after the TVA model of the USA, no systematic study has been done to review the post-DVC situation. There are several official papers and documents highlighting positive impacts of the DVC in general, but no attempt has been made to assess other aspects of this project. There are several research articles, published from various countries, which focus on flow regime, riparian ecosystem and sedimentation patterns below major control points. None of these, however, mention social relevance of control structures at a local level within the riverbed. As here focus is on socio-economic issues emerging from control structures, there is no a priori model for the present study.

Textbooks on geomorphology by Wooldridge and Morgan (1959), Thornbury (1954), Sparks et al. (1972) are rather reticent about methods of enquiry in geomorphological research. Traditional textbooks do not contain a separate chapter on applied geomorphology. Thornbury's book (1954) does not discuss methods of enquiry. King (1967), in his introductory chapter, covered the methods of study. He mentioned four research methods: theoretical, observational, experimental and empirical. According to King, observation in the field plays an important part in geomorphological work. Here, the method is observational to a great extent, but not necessarily descriptive. Pitty (1982), in his book entitled "The Nature of Geomorphology" stated clearly that in applied geomorphological research the method has to be idiographic as applied problems are location and culture-specific. King distinguishes research methods from methods of analysis. He states that, "One of the methods used in the development of the geomorphological argument is the inductive method. By this means a series of facts is arranged in a logical order so that one leads to another and then to the final conclusion which follows a reasonable and accepted way from the data set forth. In this method observations are used to draw conclusions as the argument is built up" (King 1967, p. 25). This inductive method requires a large number of case studies on a single theme for identification of similar phenomena, comparison of findings, and, ultimately, formulation of a theory (Beaujeu–Garnier 1976). Following King, Beaujeu-Garnier and Pitty, the method of analysis used here is idiographic or inductive. The deductive method has also been used to assess the selected hydrogeomorphic consequences of dam closures.

2.13 Spatial Scale and Time Scale

As applied issues are location and time-specific, the study area has to be small so that problems can be studied intensively. In this study, the space selected is the Lower Damodar River below major control structures although observations have been made on the adjacent riparian tracts tangentially to fortify some of the arguments. The time scale, broadly speaking, is from 1665, but major observations on flood behavior are from 1730 onwards. For analysis of the impact of control structures on selected hydro geomorphic parameters, the time scale ranges between 1933 and 2007. For the analysis in the changes in the riverine regime of the Lower Damodar River, the time scale ranges between 1854 and 2008.

2.14 Technique and Tools

Selection of techniques and tools varies with research perspective, method of analysis and spatio-temporal scale but sometimes a researcher is forced to use outdated techniques due to non-availability of required tools.

Wooldridge and Morgan (1959) contend that geomorphology must begin at home if the student is to cultivate the "eye for country" which alone can make him a master of his medium and free from the limitations of book knowledge. This statement is relevant in theoretical research, but more important in applied geomorphology. Even King (1967) has devoted a special chapter to "Field Techniques". Despite improvement in techniques and tools, almost all researchers or authors in geomorphology have focused on field survey techniques. Field techniques have been emphasized in this study for several reasons. First, micro-relief forms are not observable in generalized Survey of India (SOI) or other maps. Second, these micro landforms are so dynamic that they required field visits several times. Third, due to non-availability of or inaccessibility to air-photographs and Landsat imagery for all sections of the river, field survey techniques became imperative for collection of active data from repeated visits. Fourth, continuous data on land use in the riverbed is not available in government institutions. Therefore, frequent field visits were conducted to collect data on land use and river bed landscape characteristics, as this is a significant issue in this study.

2.14.1 Perception Survey

Land use, to a great extent, is the reflection of one's perception about the given environment which is physical as well as socio-economic. Clayton (1971) and Craik (1970) have discussed the concept of perception and humans' perception of the physical environment in their articles "Reality in Conservation" and "Environmental Psychology – New Direction in Psychology". Therefore, one of the techniques applied in the present study is the field survey technique through perception survey. The total number of sandbars in the Damodar is about 23. Each sandbar consists of several mouza or villages. The largest one, Bara Mana, consists of eleven mouza maps, and each one consists of several sheets. The total population of river-bed char land is approximately 50,000 and 1% were surveyed (Plate 2.2a–c). Most of the Bangladeshi refugees have been granted land deeds. They were very apprehensive about the research objectives and were reluctant to provide data on land area and crop production. Statistical techniques have been widely used in reviewing flow regime, flood behavior, and sedimentation characteristics of the Lower Damodar in the pre-dam and in the post-dam period.

2.14.2 Tools Used

Tools used in this study include SOI maps, Cadastral or Mouza (A land-settlement division of an area) maps, the 1994 Satellite Image (IRS-IB LISS-2/FCC/classified image, 1:100,000), collected from the Regional Remote Sensing Unit, Kharagpur, IRS Geocoded Imagery of 1992 and 1999 (1:50,000) from the National Atlas and Thematic mapping organization (NATMO), and for 2003 LISS-3 scenes of IRS-1D satellite (spatial resolution: 23.5 m) digital data collected from the NRSA, Hyderabad. Cadastral or mouza maps have been collected from the Refugee, Relief and Rehabilitation Department (RRR&D), and also from district collectorates (Appendix A). Different types of maps, used as tools, have helped to generate data, qualified, as well as quantified. Finally, the largest set of layout plans prepared by Refugee Relief and Rehabilitation Department (RR&RD) and data on socio-economic aspects has been generated from field surveys between 1993 and 1998 and during 2000, 2001, 2007 and 2008. Reconnaissance survey was done between 1990 and 1992.

2.14.3 Detailed Mapping for 5 Years (1993–1997) and Updated During 2000 and 2001, 2007 and 2008

The topomaps come in four different scales – 1:63,360, 1:50,000, 1:25,000 and 1:15,000 and need to be converted to a uniform scale to facilitate comparison. To achieve this, base maps have been prepared by copying the relevant information from topographical maps of three series: 1914–1932 (1:63,360), 1958–1970 (1:50,000) and 1982–1986 (1:25,000) and also from more than 100 sheets of 90 mouza maps. SOI map of 1:15,000 has been used for the section of the Lower part of the Lower Damodar River. IRS Geocoded imagery of 1992 and satellite image of 1994 [IRS-IB LISS-2/FCC/ classified image (1:100,000)] and 2003 LISS-3 scenes of IRS-ID satellite (1:100,000) have been used for some sections. To trace the evolution of channel bars, bank lines and historical planform evolution, Survey of India (SOI) maps of 73 M/7 N.E., 73 M/7 N.W., 73 M/7S.E. (1:25,000), 73I/10, 73I/14, 73 M/2, 73 M/6, 73 M/7, 73 M/11, 73 M/12, 73 M/15, 73 M/16. 79A/4, 79 N/13, 79 N/14, 79 N/15, 79/B2 and 79B/3, (1:63,360; 1:50,000), 73I, 73 M, 73 N (1:250,000) have been used. The Dickens's map surveyed in 1854 (1:126,720) has also been used. More than 100 sheets of 90 mouza maps (Cadastral survey (CS) maps, surveyed between 1917 and 1920, Revision Survey (RS) map surveyed between 1954 and 1957 and layout plan (unpublished) surveyed between 1994 and 1996 by Refugee Relief and Rehabilitation Department (RRR&D) of the Government of West Bengal and later modified with field survey between 2007 and 2008 have been consulted (Appendix A). Different sets of maps have been prepared to provide results on characteristics and changes in river channel boundary, planform characteristics, and formation and evolution of sandbars and land use characteristics in riverine sandbars and in places within the active riverbed. Other maps, such as geological maps and DVC maps, have been sparingly used. It is admitted that SOI maps are not geomorphological maps; therefore, there may be discrepancies in the data collected from these maps. The same statement is applicable to the archival maps of Barros 1550; Gastaldi 1561; Hondivs 1614; Blaev 1645; Cantelli Da Vignolla 1683; Vanden Broucke 1660; G. Delisle 1720–1740; Izzak Tirion 1730; and Rennell 1979–1781 (Sen 1962).

2.15 Selection of Variables and Indicators

Of the four independent variables – time, initial relief, geology, and climate – that influence two important hydro-geomorphic parameters such as streamflow and sediment load, time and climate have been selected as variables in impact analysis of control structures. The other two variables have no significance in the present study. Variations in quantity, as well as type of sediments can be well observed within a graded time span. Seasonal changes in climatic parameters are well reflected in streamflow and sedimentation. To assess the impact of control structures, the variables selected are streamflow and sedimentation. In assessing the riverbed land use characteristics, agricultural crops and settlements are the most important variables selected for this study.

Verstappen (1977) mentions that cultural features such as domesticated vegetation, settlements, roads, and cultivated fields are effective geomorphic indicators in the analysis of dynamic landscape. Indicator investigation was taken to a new level in the former USSR. Indicators were used to evaluate the prediction of indicated processes having different effects on landscape. Vegetation is often used as a direct indicator of depth and mineralization of shallow water (Abrosimov and Kleiner

1973). Viktorov (1973) says that human-made indicators, such as indicators that have emerged due to human activity, are significant in the analysis of landscape. In examining the applied issues and in interpreting riverbed landscape, human-made indicators such as vegetation, crops, and settlements have been considered viable indicators in this study (Bhattacharyya 1998, 2009).

2.16 Data Base and Data Constraint

Four sets of data form the basis of the present study. Archival data from old maps and government reports and records have been profusely used to trace the changing course of the Lower Damodar and its flood history. Archival data has again been used to trace the history of embankments, the first control structures. Quantified data on streamflow, sedimentation, rainfall, and cross sections has been collected from various departments of the Damodar Valley Corporation (DVC), the Irrigation and Waterways Department (I&WD), Government of West Bengal, the Damodar Canals No. 11, Subdivision–Rhondia, and the Central Water Commission (CWC) at Maithon. Hydrological data are also available in published form from the record of UNESCO (1971a, b, 1979, and 1985) and also from the report of National Commission (1980) on Flood (Appendix B).

2.17 Chapter Organization

The first chapter clarifies the research theme and perspectives. The second chapter deals with introduction, conceptual background, objectives, and various methodological aspects. The third chapter reviews the state and community level effort in flood and water resource management and impacts of embankment. The fourth chapter focuses on the reservoired Lower Damodar River from a hydrogeomorphic perspective. The fifth chapter concentrates on the colonization processes in the Lower Damodar riverbed. The sixth chapter discusses the controlled Lower Damodar River from a social perspective. The seventh chapter reviews the controlled lower Damodar as a product of twin processes: hydrogeomorphic processes and anthropogenic land utilization processes, and in the eighth chapter, an attitude for better human-environment interactions as well as available planning approaches for future management of river resources are provided.

2.18 Working Steps

This research project began with literature survey on the Damodar River and a reconnaissance field survey in the study area. On the basis of this field survey, the research theme was selected. The next step was the collection and collation of different types of maps. The third step was to collect data from different government institutions. It was followed by an intensive field survey. Simultaneously, literature has been reviewed on various aspects of applied geomorphology and human-environment interactions so as to organize thoughts and data to meet the objectives. The next working step was to prepare charts, tables, graphs and maps. Statistical analysis of data was a part of this step. The final step was to organize observations and thought in the form of a research report. At all stages, field survey and field checking have been considered imperative.

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Chapter 3
Flood and Water Resource Management in the Controlled Tropical River Damodar

Abstract The Damodar River, a subsystem of the mighty Ganga system, has always been notorious as a calamitous river like the Hwang Ho of China and the Kosi of India. People as well as governments throughout the centuries have dealt with the caprices of these vital water resources using different strategies. In the case of the Damodar, heavy embankments were used in its lower sector to reduce flood hazard in the Rarh plain. When the Damodar Valley Corporation (DVC) was first conceived and modeled after the Tennessee Valley Authority (TVA) of USA in 1948, the river was again controlled, this time through the construction of sophisticated engineering structures. This chapter focuses on the hydrogeomorphic consequences of lateral control structures. The riverbed has been raised, soil composition in the adjacent riparian tract has been changed, cross sections have been increased, and a number of spill channels have been opened on the right bank. In addition, shifting of banklines and bank erosion are observed on the left bank.

Keywords Bank erosion · Bank lines · Cross sections · Damodar valley corporation · Embankment · Riparian community · Riverbed · Tennessee valley authority

3.1 Tropicality of the Lower Damodar Environment

The Damodar is referred to as a tropical river as it flows through a tropical environment. Tropicality of environment is assessed in terms of specific conditions and not by mere latitudinal location. The tropicality of environment is primarily a product of thermal criteria. Further classification is based on amount and seasonality of precipitation.

The basic tropical climatic characteristics of the drainage basin are the following:

i. The temperature of the coolest month (December) is 19.15 and 19.85°C at Asansol and Barddhaman, respectively (Tables 3.1 and 3.2)
ii. The average seasonal ranges are 13.95°C (May and December) and 11.85°C (May and December) for Asansol and Barddhaman respectively

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Table 3.1 Climatological table of Asansol (based on observation from 1931–1960)

	Temperature in °C			Wet Bulb temperature				
Month	Highest	Lowest	Mean	in °C	in °F	Relative humidity	Total rainfall	No. of rainy days
Jan	29.5	08.5	19.00	14.45	58.01	56.0	16.6	1.3
Feb	33.1	10.3	21.70	16.10	60.98	50.5	24.3	2.2
Mar	39.1	14.9	27.00	18.70	65.66	37.0	17.3	1.8
Apr	42.8	18.9	30.85	21.85	71.33	38.0	23.9	1.3
May	44.5	21.7	33.10	24.95	76.91	52.0	73.0	4.8
June	42.6	22.9	32.75	25.80	78.44	69.5	192.4	7.3
July	35.3	23.6	29.45	26.40	79.52	82.0	344.4	18.2
Aug	34.4	23.7	29.05	26.35	79.43	84.5	335.3	17.6
Sep	34.7	23.1	28.90	26.05	78.89	81.5	234.8	11.4
Oct	34.1	17.6	25.85	23.50	74.30	73.0	112.9	5.4
Nov	31.7	12.1	21.90	18.10	64.58	61.0	14.8	1.0
Dec	29.2	9.1	19.15	14.90	58.82	57.5	2.5	0.2

Source: IMD Climatological Tables of Observatories in India (1931–1960).

iii. The average daily range of temperature is greater than seasonal range of temperature
iv. Monthly rainfall varies from 2.5 mm (December) to 344.4 mm (July), 4.3 mm (December) to 314.4 mm (July), and 3.2 mm (December) to 331.9 mm (August) for Asansol, Barddhaman and Hooghly respectively (Tables 3.1 and 3.2)
v. The Lower Damodar Basin has an annual rainfall of 1,321 mm (western upland area) to 1,600 mm (eastern and south eastern part), Fig. 3.1
vi. There is a definite dry period from November to May
vii. There are five rainy months, from June to October, which account for more than 80% of the total annual rainfall
viii. Relative humidity is more than 80% in July–September, and only 50% or less than 40% in March and April
ix. The number of rainy days increases from June to August
x. The annual rainfall is variable, the co-efficient of variability being 106.07%.

The above conditions conform to the requisite conditions for a tropical climate as defined by Thronthwaite in 1931, 1933, 1948, Köppen in 1931, 1936 and also by Trewartha (1968), Barry and Chorley (1978) and Nieuwolt (1977).

The monsoon tropicality of the environment is reflected on the hydrographs (Fig. 3.2). The hydrograph is leptokartic in nature. Peak discharge is generally found in the months of July–September. Discharge is low between January and May and again between November and December.

Table 3.2 Climatological table of Barddhaman (based on observation from 1931–1960)

	Temperature in °C			Wet Bulb temperature				
Month	Highest	Lowest	Mean	in °C	in °F	Relative humidity	Total rainfall	No. of rainy days
Jan	30.1	09.3	19.70	14.45	58.01	59.5	11.2	0.9
Feb	33.5	10.6	22.05	16.10	60.98	54.5	24.6	1.8
Mar	38.5	15.1	26.80	18.70	65.66	49.5	25.0	1.7
Apr	41.4	20.1	30.75	21.85	71.33	53.5	46.1	3.0
May	42.1	21.5	31.80	24.95	76.91	64.5	114.8	6.5
June	39.7	23.0	31.35	25.80	78.44	76.0	196.0	10.6
July	34.7	23.7	29.20	26.40	79.52	83.5	314.4	15.9
Aug	34.5	24.0	29.20	26.35	79.42	83.0	301.2	16.3
Sep	34.5	23.4	28.95	26.05	78.89	81.5	236.5	11.5
Oct	34.1	19.7	26.90	23.05	74.30	75.5	106.8	5.2
Nov	31.8	14.1	22.95	18.10	64.58	69.0	23.0	1.1
Dec	29.3	10.4	19.85	14.90	58.82	64.0	4.3	0.2

Source: IMD Climatological Tables of Observatories in India (1931–1960).

The tropicality of the Lower Damodar basin can also be assessed from the floristic composition. Original climax vegetation was tropical deciduous with Sal (*Shorea robusta*) predominating. Extension of coal mining activity, construction of roads,

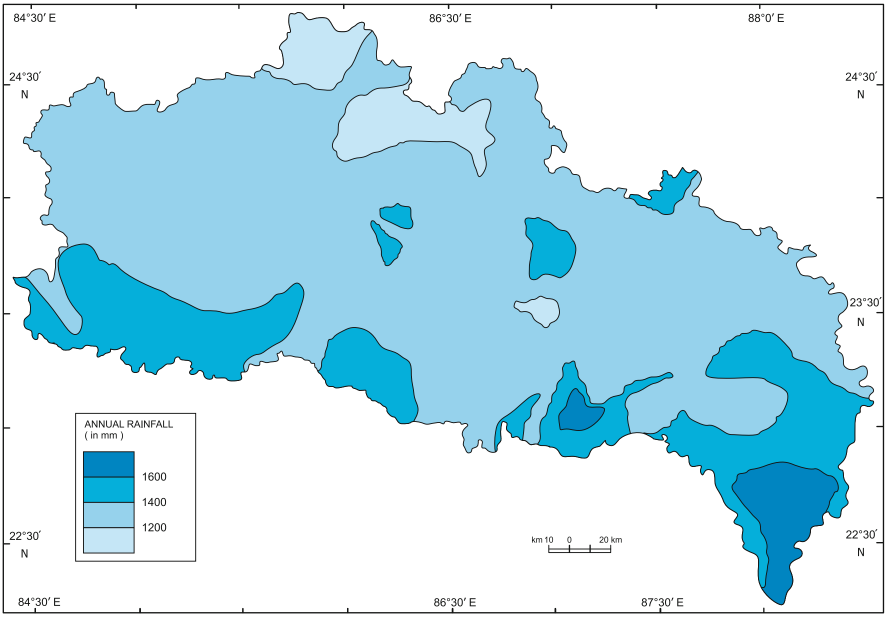

Fig. 3.1 Rainfall map of Damodar valley region. Source: Chatterjee (1969)

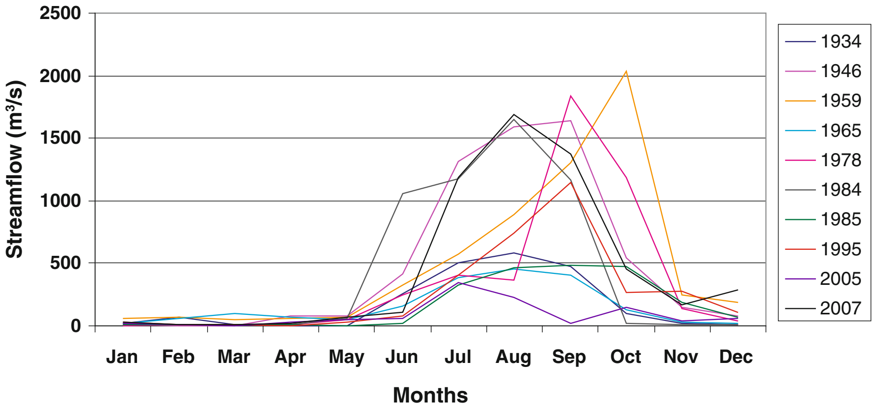

Fig. 3.2 Hydrographs of the Damodar River at Rhondia. Data source: Damodar Canals No. 11, Subdivision–Rhondia, Barddhaman

railways, barrages and reservoirs, and growth and development of urban industrial towns in the upper part of the Lower Damodar has necessitated removal of this climax vegetation. Now there are mostly open forests with coppiced Sal (Dhara and Basu 1988). By virtue of its position, the rest of the Lower Damodar basin must have been forested in the historical past. The forests were cleared long ago for agriculture. An expensive afforestation scheme has been initiated under the territorial forestry and social forestry schemes. Tropical energy plant species such as Akashmoni (*Acacia monilisormis*) and Subabul (*Leucaena leucocephala*) have been planted almost everywhere. The tropicality of the environment can also be recognized from soil characteristics.

Tropicality is also reflected in the economic activities of the region. In the entire Damodar drainage basin, human occupation varies from rock quarrying, forestry, mining, and agriculture to industrial urban activities. Agricultural land use characteristics are closely associated or adjusted with the flood-prone micro-environment. Crop selection and crop calendars strictly follow the tropical climatic regime and will be discussed in later sections. Economic activities such as open-pit mining and sand quarrying are greatly affected by heavy rain during monsoon. Transport facilities in the Lower Damodar valley area are extremely inadequate as the Grand Trunk Road, which links Kolkata (Calcutta) with Upper India, is the only important all-weather long distance road in the valley. The village roads are seasonal and almost impassable during the monsoon period using any modern conveyance. Unmetalled roads are motorable only in the dry season i.e., from November to May. Seasonal rivers are fordable during the dry season as ferry service is rendered during the monsoon period. There are state and district highways but surface conditions deteriorate during the rainy season. All these activities, however, are not controlled by the tropical environment but are influenced, to some extent, by climatic characteristics. Jarrett (1977) also refers to the human background of the tropics while defining the tropical region.

3.2 Background of the Population Group

The studied section of the controlled Lower Damodar is inhabited by several distinct communities: local Bengalis and migrated Bengalis; migrated people from Bihar and Jharkhand; Bangladeshi refugees; and Bihari and Uttar Pradesh (UP) people with refugee status. The Biharis came from the Chhotanagpur plateau to work in the coal mines of the Ranigunj coalfields. The labor freed from disused collieries was absorbed later in the agricultural sector. People from Uttar Pradesh were originally fishermen or boatmen. Before independence, they used to ply the rivers from UP to the present Bangladesh. They probably left the former East Pakistan after 1947. The Bengali Hindus (Bangladeshi) came to India after 1947 and again after 1970. There was step migration from East Pakistan or Bangladesh. They came to the districts of Nadia and 24 Parganas first and from there they moved to the Barddhaman and Bankura districts. Biharis and local Bengalis include Muslims. The total population in the studied section is about fifty thousand approximately. All these groups are undifferentiated in one characteristic: the level of education is very low everywhere.

3.3 The Damodar – A Flood-Prone River

A flood is a high flow of water, which overtops either the natural or the artificial banks of a river channel (Smith 2001). Under pre-dam conditions, the hydrologic processes of the fluvial system create and maintain stream channels with channel maintenance maximized during bankfull discharge. Whenever streamflow exceeds bankfull capacity, and river spills over onto an adjacent floodplain, the river visits a flood stage. All rivers work in the same way suggesting that flooding is a natural behavior of a river system. Floods become hazards when these events disrupt an established routine of life, inflicting suffering and death on many who occupy hazard zones (Bhattacharyya 1991). The Damodar River is very small and is not comparable to the large rivers of the world. However, it shares notoriety with the Hwang Ho (Yellow River) of China and the Kosi of India as far as floods are concerned (Bhattacharyya 2002).

Floods have been a concern for people from time immemorial and are still significant events in developing and as well as in developed countries, although with different modes of production. Floods and flood-related issues are addressed by various disciplines such as engineering sciences, hydrology, meteorology, economics, and sociology. In geography, flood is viewed from a spatial standpoint. It is included within the province of pure or theoretical geomorphology and applied geomorphology as well. This inclusion in both fields is justifiable from somewhat different perspectives. In theoretical geomorphology, floods, flood-borne materials and flood-built features are fundamental entities, whereas in applied geomorphology they are treated as a resource or a hazard or both, depending on the combination of physical environmental parameters and socio-economic factors. Thus, they become functional entities in theoretical as well as in applied research (Bhattacharyya 1998, 2009).

Flood control structures can be seen as effective indicators of progress and development of a community or a society. Transfer of flood water from surplus regions to deficit regions and from surplus seasons to deficit seasons through control structures are in fact associated with hydraulic civilizations. In other words, the rational use of flood water can be considered one of the factors behind the progress of civilization. From documents ranging from the ancient Puranas (religious stories) and to recent government reports, it is evident that the Lower Damodar is an endemic flood-prone tropical river. Flood propensity of the river is also reflected in old maps (Bhattacharyya 1998, 2002).

Investigation of the controlled Lower Damodar begins with the flood problems that necessitated adopting flood control measures from embankments to multipurpose reservoirs. Control structures are the effects and flood is the cause. In this chapter both causes and effects are considered with equal weight. The objectives of this section are three-fold: to trace the changing courses of the Lower Damodar which lead to flooding; to trace the flood history of the Lower Damodar; and to trace the evolution of control structures both chronologically and chorologically, as well as to assess the impacts of lateral control structures. In brief, this chapter reviews the state and community level efforts in managing river resources through ages.

A flood is a hydro-geomorphological process controlled by hydro-meteorological factors in a physical environment where physical laws dictate all phenomena. However, flood control measures are taken on the basis of cultural practices and socio-economic situations that are always location-specific. Therefore, research methods here are necessarily ideographic. This does not imply that the physical parameters of flood phenomena are ignored. In fact, hydro-geomorphological information is applied to solve flood-related socio-economic problems. At flood stage, a river crosses its normal boundary inundating a large part of its valley floor and expanding spatially. The spatial scale of the Lower Damodar has varied in different flood years and this variable spatial scale must be considered when floods and flood-related issues are examined.

The flood history of the Damodar has been traced for a time span of 342 years from 1665 to 2007, although recorded flood history dates back from 1730. Embankments, the first control structures on the Lower Damodar, were mentioned in the government report of 1852 (Ricketts 1853; Voorduin 1947; Bhattacharyya 1998, 1999–2000a). This report states that the embankments are a century old, indicating that the embankments were in existence from 1752. The Rangamatia dyke or dam, the last control structure in the studied section, is 14 years old. Therefore, the time span between the first control structure and the last control structure is 244 years. Although most of the data is obtained from government reports and records, data has also been generated and inferences drawn from old maps. The first recorded information on the Damodar embankment is available from 1846 onwards (Sage et al. 1846; Bhattacharyya 1998, 2008b). For later years, data from the DVC has been used. There is, more or less, a continuity of data on control structures and other hydrological information from 1933 onwards.

3.4 Changing Courses of the Lower Damodar

The Lower Damodar had an extensive delta formation which was older than the Ganges-Brahmaputra-Meghna delta. The changing courses of the Lower Damodar exemplify the shifting of rivers in an unstable deltaic environment. Shifting of channels, needless to say, is always associated with avulsion and floods (Bhattacharyya 1998).

The early maps of Jao De Barros, 1550; Bleav, 1645; Vanden Broucke, 1660; Rennell, 1779–1781 and maps and charts of other unknown cartographers provide cognizable evidence of the changing courses of the Lower Damodar (Fig. 2.5). Superimposing the present river system on the river shown in the Rennell's map (1779–1781), some trend lines can be obtained. One course bifurcates from Selimabad and flows in a south-easterly direction and then in a north-easterly direction before entering into the River Bhagirathi near Noaserai above Tribani. The main flow is found in a southerly direction, passing through the Amta channel and falling into the Hooghly River. Another old course, which can approximately be identified with the present Gangur River (Sen 1962), flows in an easterly direction below Barddhaman, meeting the Bhagirathi River near Kalna.

According to De Barros (1550), the main flow of the Damodar in the sixteenth century was restricted to the present Kana Damodar channel taking off below Selimabad and meeting the River Hooghly at Uluberia. Vanden Broucke's map from 1660 shows the main channel of the Damodar flowing through the Moja Damodar and meeting the River Rupnarayan near the present Bakshi Khal. At the same time, a large branch used to flow through Barddhaman, apparently along the line of the present course of the Gangur and Behula River, falling into the River Bhagirathi near Kalna. In the Bengali folk story "Manashar Bhasan" (1640), it is stated that the dead body of Lakhindar, the hero of the epic, was taken by his wife Behula in a boat along this river. This story reveals that in that period (1640), a great volume of the Damodar water used to pass through this route (Das K and Das K 1885). In the same period (1660), a smaller branch of the main Damodar used to flow through the Amta channel falling into the Hooghly River opposite Falta and was known as the Mondal Ghat River. This was shown as a small creek in a chart from 1690. Shortly after 1660, the Damodar deserted the Gangur–Behula branch and the Kana Damodar became the main channel. Subsequently, another branch opened along the Kana and Kuntinadi. The Kana Damodar in that period entered Noaserai, 4.81 km above Tribeni and 62.76 km above Howrah. It showed deterioration owing to the diversion of its supply to Kana Nadi. In the maps and accounts of the seventeenth century and the beginning of the eighteenth century, the Kana Damodar was called the Jan Perdo River, i.e. a river for large ships (Census 1961), and its importance is still attested to by the long marshes and populous villages along its bank. This Kana Damodar is represented as an insignificant creek in Ritchie and Lacam's chart of 1785 (Stevenson et al. 1919; Sen 1962; Bhattacharyya 1998, 2002).

Meanwhile, changes had taken place in the Kana and Kunti Nadi which were flowing in an unnatural direction i.e., from south-south east to north-north east. This is evident from the fact that the Saraswati River, which left the Hooghly River at

Tribeni, would have been flowing in a generally parallel but reverse direction to the Kunti Nadi. The latter must, therefore, when the Hooghly level was high, have acted as an effluent (owing to the Hooghly River backing up into it) and changed into an affluent when the periodic flood came down the Damodar (Stevenson et al. 1919; Bhattacharyya 1998, 2002).

People of the adjacent countryside, we may presume, tried to maintain the channel by constructing marginal embankments and thus giving the river an artificial and precarious existence for a period. An additional supply from the Kana Damodar was diverted into this river and the bed level rose, particularly in the Kunti Nadi which could not accommodate the supply. As a result, the volume of the main river was diverted from it (Stevenson et al. 1919). Rennell, during his survey around 1760, referred to the Kana and Kunti as the old Damodar (Sen 1962).

Although it is not recorded, tradition has it that the Damodar, which formerly flowed into the Hooghly at Noaserai, burst its embankment around 1762 (Sherwill 1858). From all this evidence of the changing courses of the Lower Damodar, we can conclude that the entire tract between Noaserai and Mundeswari was inundation-prone in the historical past (Bhattacharyya 1998, 2002). At present the Amta channel is chained with embankments restricting further shifting of the lowest part of the Lower Damodar.

3.5 Flood History of the Lower Damodar River

In old records the Damodar has always been referred to as a river of sorrow. Hunter in 1876 writes that, during floods, the rainwater used to pour off the hills through hundreds of channels with such suddenness that water heaped up to form dangerous head waves known as “hurpaban”. These were of great breadth and appeared like a wall of water, sometimes 1.5 m high, causing irreparable damage to land, property and people (Hunter 1876; Bhattacharyya 1998, 2002). The flood rose and subsided rapidly within one to 3 days. Long before Hunter, however, an anonymous poet had referred to the Damodar flood of 1665 (Mitra 1946). The first recorded flood was in 1730 (Voorduin 1947). Since then, floods of different magnitudes have occurred every 8–10 years. Floods with peak flow of 8,496 m^3/s or more occurred 37 times between the years 1823 and 2007. The records for the period between 1878 and 1912 are not complete, but floods were reported to have occurred also in 1882, 1890, 1898, 1901, 1902, 1903, 1905, and 1907. The floods of 1823, 1840, 1913, 1935, 1941, 1958, 1959, and 1978 had peaks of more than 16,992 m^3/s. A peak flow of about 18,678 m^3/s has been recorded 3 times: in August 1913, 1935 and October 1941 (DVC 1995; Bhattacharyya 1998).

The 1913 flood originated from a mean rainfall of 30.23 cm over the basin whereas a mean rainfall of 23.29 cm in 3 days caused the 1935 flood. The 1943 flood, with a comparatively low peak flow (9,911 m^3/s), resulted from a mean rainfall of 21.34 cm over the catchment. Despite low peak flow, the damage caused by this flood was the highest on record assessed on the basis of 1951 prices (DVC

1995). In the month of September 1958, heavy rainfall for 3 days at a stretch caused flooding in the Damodar and the Barakar Rivers with peak flow greater than any recorded in the past. Had there been no dams, the maximum observed peak flow at Durgapur would have been of the order of 18,537 m^3/s. The DVC reservoirs succeeded in moderating this flood to only 5,802 m^3/s. Similarly, from the 1st to the 3rd of October 1959, the Damodar and Barakar Rivers experienced another record-breaking peak flow. Without the intervention of the dams, the peak flow at Durgapur would have been of the order of 22,923 m^3/s but was actually moderated to only 9,905 m^3/s. The 1978 flood can be considered the greatest disaster of the twentieth century. The cyclonic rainstorms between the 27th and the 29th of September followed by a secondary peak between the 2nd and the 4th of October caused heavy rainfall above 500 mm in the Damodar catchment. The highest combined inflow at Maithon and Panchet was recorded as 21,070 m^3/s on September 27, 1978. This huge inflow was moderated by the dams to a combined outflow of 4,616 m^3/s. It was further augmented to 9,345 m^3/s at Durgapur and 10,919 m^3/s at Rhondia, causing widespread flooding in the Lower Bengal (DVC 1978; Sen 1985b). In 1995, and again in 2000 and 2006, the lower valley witnessed a normal flood with flows of 6,522, 6,387 and 7,035 m^3/s respectively at Rhondia. Lastly, in 2007, an abnormal flood with a peak flow of 8,883 m^3/s at Rhondia visited the lower Damodar valley. Therefore, recorded history of the endemic flood prone areas of the Damodar can be traced from 1730 onwards.

Inundations have occurred several times between 1730 and 1816, with an average interval of 13 years and with the next inundation occurring after 7 years i.e., in 1823. The next flood surfaced in 1834 after an interval of 11 years with another one following in 1840 after 6 years. Subsequent intervals were further shortened. Severe floods occurred in 1841, 1844 and 1845. Hence, within the time span of 115 years, 13 severe inundations took place, out of which 7 occurred in the first 85 years and 6 in the last 30 years (Sage et al. 1846; Bhattacharyya 1998, 1999). This increase in flooding may be attributed to the fact that, in the earlier period, overflow irrigation from the Damodar was considered beneficial for agriculture and people built and maintained canals to carry flood water to their fields. Egyptian engineer Sir William Willcocks, in his lectures delivered at the Calcutta University in 1930, stated that he considered the soils of the Lower Damodar valley one of the richest soils in the world. He further stated that travellers in 1660 used to consider central Bengal as rich as Egypt. In 1815 Hamilton passed through the districts of Burdwan (present Barddhaman), Hooghly and Howrah and described the tract as the most productive agricultural land in entire Hindustan (undivided India) (Willcocks 1930). From 1815 onwards, however, landlords and tenants of central Bengal started to neglect the irrigation canal systems. The negligence probably began in the undivided Bengal during the Maratha–Afghan war (1803–1818) and later in Barddhaman in the later half of the eighteenth century. These waterways remained neglected and unused after the wars. The British thought these waterways were for navigation only and left them as they were. As these deteriorating waterways or canals took in less amounts of water, more and more water remained in the Damodar and it grew as a menace to the riparian tract (Willcocks 1930; Bhattacharyya 1998). 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).

The flood history during the period 1857–1917 can be traced from the EL Glass report submitted to the then Bengal Government as observed at Raniganj, a few kilometers upstream of Durgapur (Sen 1962). Corresponding data for the period between 1933 and 1956 and 1959 and 2007 at Rhondia, are given in Table 3.3. During the period 1857–1917 the number of floods (between 5,664 and 8,496 m^3/s) was 33, which was reduced in later periods to 11 (1935–1956) and 5 (1959–2007) respectively. In the post-dam situation only three high floods have occurred: October 1959, September–October 1978, and September 2007.

The 1978 flood merits special mention as the most destructive flood of the twentieth century in south Bengal. The huge amount of sand deposited by the Damodar can still be seen in the adjacent villages near Gaitanpur, Panchpara and elsewhere. The riverine sand bars still exhibit sand heaps deposited during this flood. The floods of 1995, 2000, 2006 and 2007 are not insignificant compared to many other floods that have occurred in the historical past but in magnitude they cannot compare with the 1978 flood. Following Collier et al. (1996) we can say that two or three preceding flood-free decades may have been traded for this devastating flood.

Table 3.3 Flood history of the Lower Damodar River

At Raniganj (during 61 years (1857–1917) – A	
No. of extremely abnormal floods (above 12,744 m^3/s)	1
No. of abnormal floods (above 8,496 m^3/s)	12
No. of normal floods (between 5,664 and 8,496 m^3/s)	33
No. of subnormal floods (below 5,664 m^3/s)	15
At Rhondia (during 23 years (1933–1956) – B	
No. of extremely abnormal floods (above 12,744 m^3/s)	2
No. of abnormal floods (above 8,496 m^3/s)	7
No. of normal floods (between 5,664 and 8,496 m^3/s)	11
No. of subnormal floods (between 2,472 and 5,664 m^3/s)	4
At Rhondia (during 50 years (1959–2007) – C	
No. of extremely abnormal floods (above 12,744 m^3/s)	0
No. of abnormal floods (above 8,496 m^3/s)	3
No. of normal floods (between 5,664 and 8,496 m^3/s)	5
No. of subnormal floods (between 2,472 and 5,664 m^3/s)	25

After Bhattacharyya (1999).

Data source: Flood history at Raniganj during 61 years (1857–1917) has been drawn from the report of EL Glass, submitted to the then Bengal Government, cited in Sen (1962).

The annual peak discharge data for the River Damodar at Rhondia is available from 1823 to 1933 as a discontinuous series in published form from the National Commission of Flood, Vol. 2. The same data for 1934–1960 is available in published form from the UNESCO, Vol. 11, 1971 and for 1960–2007 from the Damodar Canals No. 11, Subdivision–Rhondia, Barddhaman.

3.6 Policy Recommendation by National Commission on Floods

The National Commission on Floods submitted its report (1980) after the devastating flood of 1978. The Commission made 207 recommendations in all for a comprehensive dynamic and flexible approach to the problem of floods as part of a comprehensive approach for the utilization of land and water resources. It recommended the development of prioritized measures to modify the susceptibility of life and property to flood damage. Equally important were the recommendations by the National Commission for Integrated Water Resources Development and Management Plan, 1999 regarding flood management. It was noted that the country must shift its strategy towards efficient management of flood plains, flood proofing, flood forecasting, and flood insurance. The National Water Policy of India, formulated in 1987 and then reviewed and revised in 2002, mandates an integrated and multi-disciplinary approach to the planning, formulation, clearance and implementation of projects, including catchment area treatment, environmental and ecological aspects, the rehabilitation of affected people and command area development. While physical flood protection like embankment and dykes will continue to be necessary, increased emphasis should be laid on non-structural measures for minimization of losses, and reduction of recurring expenditure on flood relief (DVC Interin Report 2008, personal communication with Ray C, February 15, 2008).

3.7 Phases of Controlling the Lower Damodar

The flood-prone Damodar River has necessitated construction of control structures from very ancient times: “In uninhabited regions the rivers are wayward and restless, ever shifting from place to place within the bounds of the valleys that are theirs to sprawl across at will ... But as soon as a country acquires a settled population this unstable habit of running water is corrected. For many reasons, human interests demand that a stream shall have a fixed course” (Lamplugh 1914, p. 651). The validity of this statement with regard to the Damodar cannot be denied as rivers were also restless over the Rarh plain which was populated even in the distant historical past by a highly civilized community known as Gangarides, or Gangaridaes (Basu 1989). Since agricultural prosperity in the region has continued for centuries, it is fair to presume that flood control measures in the Lower Damodar were taken long ago, one of the earliest control measures being embankments. It is most likely that those ancient embankments were non-engineered earthen embankments that have been totally destroyed due to shifting of rivers. A geomorphological map prepared by Niyogi (1978) shows the palaeo-channels and old levees. It is unfortunate that the literature has discussed the shifting courses of the Lower Damodar but has remained silent about embankments. Therefore, the discussion on control structures begins with embankments that have been mentioned or shown in government reports or in old maps.

3.7.1 Embankments

The origin of embankments constructed on the Lower Bengal Rivers is difficult to trace. The embankments along the Damodar River were most probably constructed by local landlords to protect their land and property from floods (Gastrell 1863; Bhattacharyya 1998; 1999–2000a). These embankments were intended to save the paddy crop, the main crop of Bengal, as well as to protect the towns and villages (Sengupta 1951). According to Kapil Bhattacharyya (1959), a hydraulic engineer, these embankments are 4,000 years old.

3.7.1.1 Zamindary Period

It is difficult to trace exactly when and where flood disaster abatement measures were first adopted. It is clear, however, that these embankments date to a period before the British rule (O'Malley and Chakravarti 1909; Bhattacharyya 1998, 1999–2000a). Earlier papers refer mainly to the condition and management of the embankments which, in January 1852, were said to have existed for a century (Voorduin 1947). In 1760, the districts of Barddhaman and Medinipur were ceded to the East India Company. They already contained embankments at that time, the most important being those within the Burdwan Raj Estate i.e., within the present Barddhaman, Hooghly and Howrah districts (O'Malley and Chakravarti 1912). This system of embankments was never very extensive along the river bordering the Bankura district as the main channel here was quite broad and shallow and sufficed to carry off most of the flood waters (Gastrell 1863). It was the duty of the local landlords to secure their lands from inundation by renovating or repairing the embankments, locally known as *pulbandi* measures. Detailed quantified information about these zamindary embankments is not available but it may be assumed that a uniform system of bunding the river had never been thought of. The report of the embankment committee formed in 1846 states that these embankments were irregular and levels were uncertain. If one portion of the embankments was 0.91 m above the highest flood rise, the adjoining one was low enough to be overtopped or breached during floods. Initially these embankments were not even continuous, resulting in devastating floods when the floodwaters of the Damodar rushed in through the gaps between them. The maintenance of embankments was inefficient and neglected (O'Malley and Chakravarti 1912; Bhattacharyya 1998, 1999–2000a) and breaching of embankments was a regular phenomenon. The cost of repair was realized by the zamindars from the tenants concerned.

3.7.1.2 British Period

It is difficult to distinguish the government embankments from the zamindari embankments until 1833. In 1836 the embankment question was taken up seriously by the British Government. In 1840 the town of Barddhaman was submerged under water three times in a single year due to breaching of the left bank embankments in 113 places. Willcocks stated that these were all secret breaches by farmers to take flood water into their fields (Willcocks 1930). In 1845 about 89 masonry sluices were constructed in lieu of cuts that were formerly made by people or landlords. In 1846 the general question of embanking the rivers was reviewed by an expert committee. The committee report began with the statement that all the rivers should be kept unconfined. The committee further recommended the total removal of embankments (Sage et al. 1846). Concern was expressed about the role of embankments in gradual shallowing of the river thus augmenting flood propensity in the lower reach. There were correlated fiscal issues regarding maintenance of embankments. Questions were also raised about the neighboring flood basin being deprived of fertile silt (Sage et al. 1846) due to embankments. The land between the embankments and the river were considered valuable and landlords sometimes moved the embankments a mile off the river. The owners of the land left outside the embankments, despite gradual deterioration of the land, had to pay a higher rent (Ricketts 1853). Several committees were formed to investigate issues such as increased sedimentation on the riverbed making the river shallower, increase in flood propensity due to shallowing of the riverbed, unhappiness of landlords about cost of maintenance of embankments, restriction of lateral spread of flood water thus depriving the adjacent plain from flood-borne fertile silt, reluctance of landlords to pay higher rent for these silt-deprived so-called protected lands, and removal of embankments as the solution to these problems.

It is noteworthy that all of these problems had a very strong applied connotation. Embankments were constructed for the benefit of flood-affected communities. It is ironic that, on the basis of observations on embankments, river discharge, and river bed sedimentation, several proposals were made to remove embankments for the benefit of the same riparian communities (Bhattacharyya 1998).

Proposal for Removing the Right Bank Embankments

Beadle, a secretary of the then Military Board in 1852, proposed that the right bank embankments of the River Damodar be removed in order to relieve the works on the left bank. He observed that, on the right bank, the land rises a short distance from the river and slopes down towards its junction with the Hooghly River. Therefore considerable space on the left side would be inundated if the embankments were removed from both sides (Ricketts 1853; Bhattacharyya 1998). Baker (1852), a consulting engineer of the then railway department, commented that the channel between the embankments was quite inadequate for discharging enormous quantities of floodwater. During floods, 18,275 m^3 of water per second had to be disposed off at an average velocity of 0.91 m/s, and for that a channel with 3.2 km width and 6.1 m depth was required. But nowhere was the river 3.2 km wide. These earthen embankments were not strong enough to keep such a flood within the channel. Barker also proposed the maintenance of embankments on the left side but removal of embankments on the right side, wherever necessary, to admit a free efflux for floods in that direction. Goodwyn, a superintending engineer of the then South East Province, based his conclusion on the assumed power of water to scour out and deepen the channel when it was contracted laterally. In his support he quoted the

Italian engineer Guliemini: "if we restrict river's bed by art, we cause it to deepen its bed, while if the bed is too wide, or divided into several branches, its bottom will be raised in proportion" (Goodwyn 1854, p. 47). He referred to the features of the country as being unfavorable to the project of removing the embankments on the right bank of the Damodar and deprecated any such measure as unnecessary and fraught with dire consequences to the country. Dickens (1853), an assistant secretary of the then Military Board, pointed out that the capacity of the Damodar was deteriorating from about 25.6 km west of Barddhaman to Amta. It could not carry one-eighth of the flood discharge received from the upstream reach. He mentioned that the breaching of embankments in 1840 in 113 places was due to the diminution in the capacity of the channel from Sungutgolah, a few kilometers west of Barddhaman to Amta. He added that no breach had occurred above Sungutgolah in 1840. Passing through the sandstone-rich Gondwana sedimentaries with high rate of declivity and in a district liable to heavy falls of rain after long intervening periods of dry weather, the Damodar is subject to heavy floods and brings down an enormous quantity of sand upon the plains. The river does not improve by closure with embankments as sufficient velocity cannot be obtained by that means to transfer excess water and sediment downstream. Any complete and permanent measures for securing the country on both banks from inundation were not possible. An observation was then made on the effect of removing the bunds from the right bank and it appeared that though the tract on both sides would be liable to heavy floods, floods would be less severe than before and the flood level of the River from about 8 km west of Barddhaman downwards would be reduced by from 2.44 to 1.22 m rendering the embankments on the left bank comparatively safe (Dickens 1853; Bhattacharyya 1998). It was finally concluded that the removal of the right embankment for about 32.2 km would provide complete security to the left bank. Colonel Garstin (1854), the then officiating chief engineer, pointed out that the system of embankments in this part of the country was not satisfactory and this system should never have been adopted. But he realized that the abolition of the vicious system which had been allowed to grow and extend itself was not an easy matter and many points must be considered and different interest groups consulted before any viable recommendation could be made. Garstin did not realize that it would injure the railways if the bunds were abolished on both banks of the Damodar. He ultimately recommended abandonment of the bunds on the right bank of the Damodar as the best measure. The opinions expressed by different technical experts on the embankment issue reveal that all of them had doubts about the efficiency of the ill-defined and mal-constructed embankments as viable flood control measures. In addition, they were particularly vocal on the issue of removal of the right bank embankments.

Removal of the Right Bank Embankments

The Bengal Government recommended the adoption of Colonel Garstin's view. In May 1855 orders were received from the supreme government for the demolition of 32.19 km of the right bank embankment from Sungutgolah down to Begua (Figs. 3.3

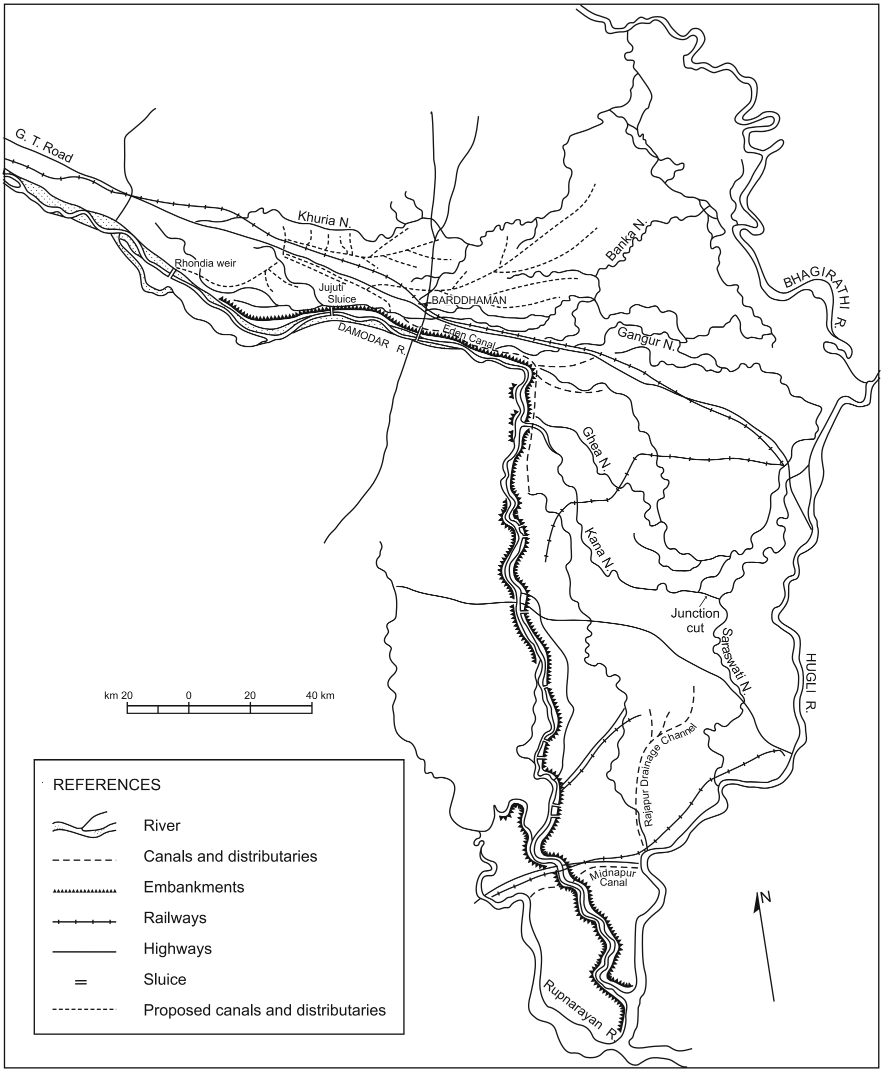

Fig. 3.3 Phases of controlling the Damodar River (British period, 1908–1946). Source: Bhattacharyya (1998, 1999–2000a)

and 3.4) for flood control and for the safety of the continuous line of left bank embankments which afforded complete security to the town of Barddhaman, the East India railway line, and the populous districts of Hooghly and Barddhaman. Before the flood season of 1959, 32.19 km of the right bank embankments from Sungutgolah down to Begua were removed. Only the embankments parallel to the river were removed whereas embankments at shoulder angles or those where the banks were low or of loose formation were left in place. In some cases embankments were strengthened and put in order. On the right bank, with the exception of a

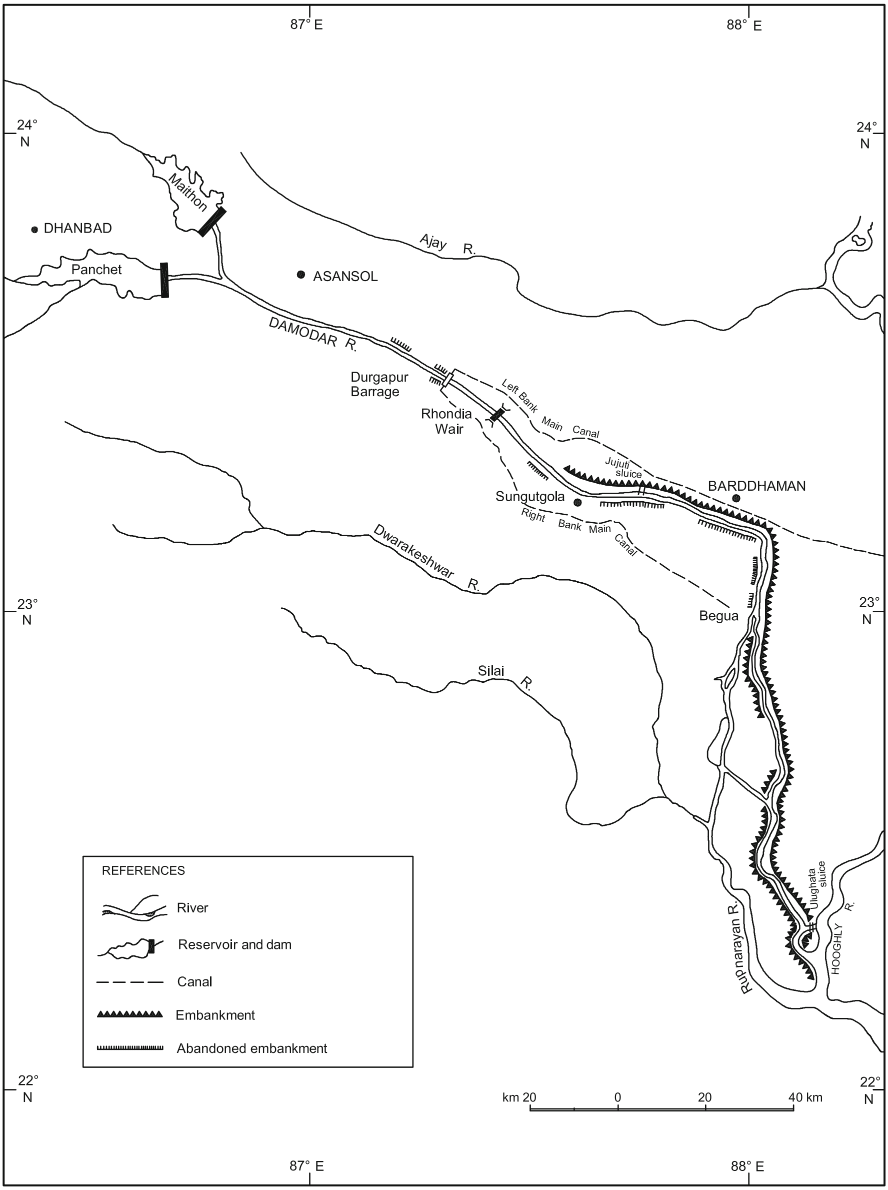

Fig. 3.4 Phases of controlling the Damodar (post British period). Source: Bhattacharyya (1998, 1999–2000a)

continuous line of 28.8 km from the Begua breach to the villages of Deboorsoot and a few detached short lengths of no importance, the embankments were completely removed. In 1889 another 16.1 km of the right bank embankments were removed (Voorduin 1947; Bhattacharyya 1998, 1999–2000a).

Proposal for Remodeling the Left Bank Embankments

There were several recommendations on remodeling the left bank embankments and some of the recommendations were translated into action. Between 1856 and 1860, the zamindars' embankments along the left bank of the river were realigned and reinforced. The left bank embankments were made continuous for 176.87 km and were provided with many sluices (Biswas and Bardhan 1975; Bhattacharyya 1999). The great Damodar floods affected the river levels at Calcutta (present Kolkata) due to cross-country spill from Barddhaman and flow from the Kana nadi. The Kana nadi was first closed at its head in 1853 by the construction of the left bank embankment that breached in 1856, and was left open until 1863, when once again it was completely closed by a bund over which the metalled road from Memari was laid (Stevenson et al. 1919).

At present, there are double embankments at Amirpur, Gaitanpur, Jujuti and areas above Paikpara. Due to severe bank erosion at these places, the embankments are being eroded. Therefore, these flood jacketting measures have been taken. Embankments have also been constructed on the left bank above the Durgapur Barrage near Andal due to excessive bank erosion. Initially the embankments were made of locally available mud and had little vegetal cover. Now, however, they are protected by laterite and basalt slabs on the inward side in many places. Strip plantation on the embankments has provided further protection and the embankments are also covered with morums. The embankments are not only important landforms in an otherwise monotonous landscape but are also a significant part of the rural resource base. People take shelter on the embankments during floods. They use the flat surface of the embankment for drying paddy and other cereals. Embankments form important transport links between villages although these are motorable only in the dry season. Embankments are lined with energy plants such as Eucalyptus and Akasmoni. In a way embankments have become an important resource base in the rural economy.

3.8 Weirs, Sluices and Canals

The bed of the Damodar River is considerably higher than the water level of the Hooghly and there are several natural water courses draining the country between the Damodar and the Hooghly into the latter. Sluice gates of a type that takes off only the top water of the Damodar during floods were fixed to the embankments near the upper reaches of these water courses. The left bank embankment has been provided with many sluices. The most notable one is at Kamarul constructed in 1883–1884. A channel inside the sluices was excavated in 1889–1890. 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 1873, the first step towards the construction of the canal was taken up by opening the head of the Kana nadi. In 1874, cuts were made connecting the channel with the Kana Damodar River and the Saraswati River. The complete scheme consists of a head sluice at Jujuti to admit water from the

Damodar River to the Banka nala, the abandoned channel of the Damodar. Water flows along the Banka nala for 11.27 km up to Kanchannagore weir and then is admitted into the Eden canal by an anicut. Therefore, the canal runs parallel to the left bank of the Damodar River for about 32.2 km, diverting the water into the Kana Damodar at Jamalpur where a head regulator was built in 1874. There was also a cut connecting the Kana nadi with the Saraswati near Gopalnagore (O'Malley and Chakravarti 1912). 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 Barddhaman district. It is known as the Anderson weir and has a length of 1,143 m. The main Damodar canal is 42.55 km with a branch canal of 34.51 km and a network of distributaries and village channels totaling a length of 344.78 km.

3.9 Post-British Period

A full century before dam closure, Dickens (1853) looked into the possibility of storing instead of trying perennially to build defences against floods in the Damodar. He was supported by Garnault in 1864, by Horn in 1902, by Addams Williams in 1814 and by Glass in 1918–1919. The foresight of these Bengal engineers was remarkable (Hart 1956). In order to alleviate the distress which was caused to the inhabitants by the removal of the right bank embankments, a proposal for storage reservoirs in the upper reaches of the Damodar and the Barakar was considered between 1864 and 1866 (Horn 1902), but measures for control of floods in the Damodar Valley received top priority only after the devastating flood of 1943. A medium flood with a peak flow of only 9,912 m^3/s breached the Damodar left bank embankment near Amirpur, a few kilometers downstream of Barddhaman, on the night of 16/17 July 1943. The river forced its way through the breach as the slope was much more favourable. Water passed through an old and abandoned course of the river and flooded the country on its way towards the Bhagirathi near Kalna. Water levels rose up from 1.83 to 2.13 m and the entire rail, road and telecommunication system was totally disrupted (Hart 1956; Mookerjea 1992). The Second World War was then at its height and the INA (Indian National Army) under the leadership of Netaji Subhas Chandra Bose was advancing towards India from Burma (presently Myanmar) during 1943 with active support and help from the Japanese Government. Because of the disruption of the rail, road, and communication facilities from North India, all the army installations at Kolkata and in eastern India were isolated having lost all logistics support. The situation was so critical that the British Government had to adopt a "scorched earth" policy and retreat from Kolkata towards the Panagarh base and ultimately to Ranchi, the headquarters of the Eastern Command. The then Bengal Government had also set up the Damodar flood Enquiry Committee to advice on permanent measures to control floods in the Damodar (Mookerjea 1992).

3.9.1 Damodar Flood Enquiry of 1944: Conception of the DVC

The Damodar flood enquiry committee met for the first time on 17th January 1944 and submitted its final recommendation by March 10, 1944. The committee, under the chairmanship of Maharajadhiraj Bahadur Uday Chand Mahtab, king of Barddhaman, did magnificent work during the period of 3 months and paved the way to the creation of the DVC, a corporate body for the solution of river basin problems affecting two states, Bihar (present Jharkhand) and West Bengal. During this time, the Tennessee Valley Authority (TVA) had been set up for taming of the wayward River Tennessee in the USA and had produced a model of an integrated river basin development project for the world showing how rivers with more or less similar features could be controlled with the help of different types of engineering works constructed in the river basin. It also demonstrated the need and utility of soil conservation measures, including erosion control and afforestation in the catchment to arrest depletion of soil and retention of run-off in the river catchment. In fact, the TVA model later became the standard engineering practice for the moderation of floods (Report 1944; Mookerjea 1992; Bhattacharyya 1998). There are numerous examples of projects that followed the TVA model in developing countries including the Damodar Valley in India, the Volta River Project in Nigeria, and the Aswan Dam on the River Nile in Egypt (Hey 1997).

The Damodar flood enquiry committee gave definite and positive recommendations regarding the construction of dams, barrages, hydro-power stations, construction of water conveyance systems for extending irrigation facilities in the Lower Damodar Valley, conservation of the Lower Damodar Valley by occasional flushing, setting up meteorological and flood forecasting stations in the upper catchment, and introduction of soil conservation and land management measures in the upper catchment through the Government of Bihar (present Jharkhand) (Report 1944; Mookerjea 1992; Bhattacharyya 1998). The Government of India then commissioned the central technical power board to study the proposal and invited W. L. Voorduin, a senior engineer of the TVA, to study the problem of the Damodar and to make his recommendation for its comprehensive development. Accordingly, in 1945 Voorduin submitted his preliminary memorandum on the unified development of the Damodar River system. He proposed construction of 7 multipurpose dams and low diversion dams on the Damodar and its main tributaries with a total storage of 5,733 million m^3 for flood control, irrigation, and power generation. The project had originally envisaged the construction of dams at Tilaiya, Maithon and Balpahari on the Barakar River, Bokaro on the Bokaro River, Konar on the Konar River, and the Panchet, the Aiyar and the Bermo diversion dams on the main Damodar River. The planner estimated a design flood of 28,321 m^3/s with a 100-year frequency. To protect the Lower Valley, it was estimated that the design flood be moderated to 7,080 m^3/s, which was the total capacity of the Lower Damodar. However, due to financial and other constraints, the participating governments of West Bengal, Bihar (present Jharkhand), and the central government approved the construction of only 4 multipurpose dams (Voorduin 1947; Bhattacharyya 1998).

3.10 Post-Independence Period

A high diversity organization known as the Damodar Valley Corporation (DVC) came into existence on 7th July 1948 as a River Basin Organization (RBO) (Chandra 2003) in India (Table 3.4) and proposed four multipurpose dams. The DVC constructed Tilaiya and Maithon dams on the Barakar River, a tributary of Damodar, in 1952 and 1957 respectively, Konar dam on the Konar tributary in 1955 and the Panchet dam on the Damodar River itself in 1959 (Tables 3.5 and 3.6).

Table 3.4 Example of RBO in India: The Damodar Valley Corporation

Inception	July 1948 by an act of the Constituent Assembly
Objectives	Irrigation and drainage; water supply; generation, transmission and distribution of electricity from hydroelectric and thermal sources; flood control; navigation; forestation and prevention of soil erosion
Integrated operation management	Damodar Valley Reservoir Regulation Committee (DVRRC) headed by Member (River Management), Central Water Commission (CWC) with representatives from DVC, Jharkhand, West Bengal
Functions of DVRRC	Develop principles for the effective regulation of reservoirs; resolve conflicts between stakeholders

Source: CWC (2001a), Chandra (2003) and Pangare et al. (2009).

Table 3.5 DVC infrastructure – at a glance

DVC Command area	24,235 km^2
Power management	
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
Sub-stations and receiving stations	At 220 KV- 11 At 132 KV- 33
Transmission lines	At 220 KV – 1,342 Circuit km At 132 KV – 3,419 Circuit km
Water management	
Major Dams and Barrages	Tilaiya, Konar, Maithon, Panchet Dams and Durgapur Barrage
Irrigation command area (gross)	5.69 lakh ha
Irrigation potential created	3.64 lakh ha
Flood reserve capacity	1,292 million m^3
Canals	2,494 km
Soil conservation	
Forest, farms, upland and wasteland treatment	4 lakh ha (approximately)
Check dams	16,000 (approximately)

Source: DVC, Kolkata

Table 3.6 DVC power plants – at a glance

Name	Location	Existing capacity	Commissioning
Hydel			
Tilaiya	River – Barakar Dist – Hazaribagh State – Jharkhand	4 MW (2×2 MW)	U-I Feb 1953 U-II July 1953
Maithon	River – Barakar Dist. – Barddhaman 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**	
Thermal			
Bokaro "B"	Dist. – Bokaro State – Jharkhand	630 MW (3 × 210 MW)	U-I Mar 1986 U-II Nov 1990 U-III Aug 1993
Chandrapura	Dist. – Bokaro State – Jharkhand	750 MW (3 × 130 MW) + (3 × 120 MW)	U-I Oct 1964 U-II May 1965 U-III July1968 U-IV Mar 1974 U-V Mar 1975 U-VI Mar 1979
Durgapur	Dist. – Barddhaman 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-1 Mar 1996 U II Mar 1998 U III Sept 1999 U-IV Feb 2005
Total thermal		2,570 MW	
Gas turbine			
Maithon	Dist. – Dhanbad State – West Bengal	82.5 MW (3× 27.5 MW)	U-I Oct 1989 U-II Oct 1989 U-III Oct1989
Grand total		2,799.7 MW	

Source: DVC, Kolkata.

The Maithon and Panchet act as control reservoirs and are located about 8 km above the confluence point of the Barakar and the Damodar. The construction of a barrage at Durgapur was started in 1952 and inaugurated in 1955 and subsidiary structures were completed by 1958 (Fig. 3.5). The barrage is about 692.20 m long. The main canal on the left bank is 137 km and the main canal on the right bank is 89 km in length. Branch and minor canals, distributaries, and drainage channels are about 2,270 km in length.

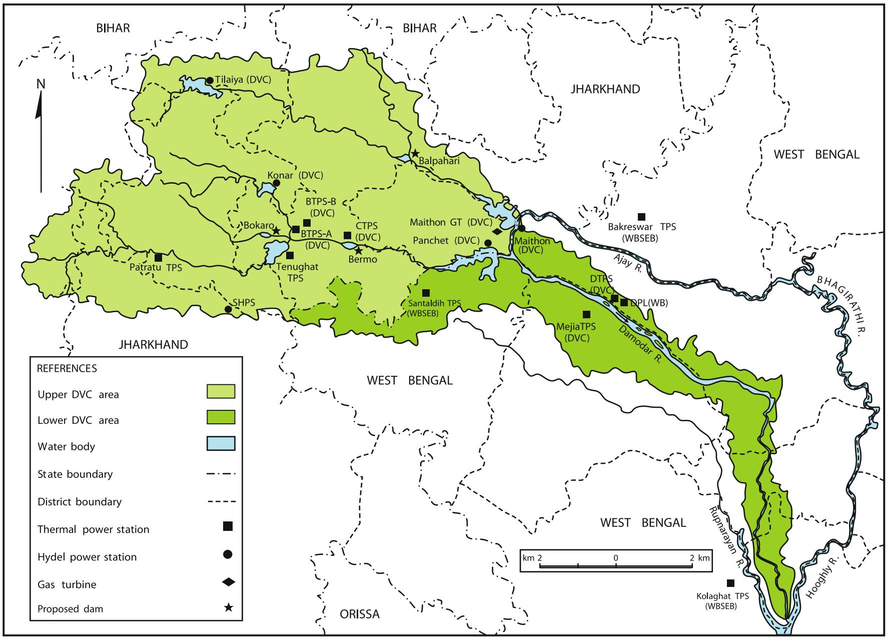

Fig. 3.5 Damodar valley region. Source: DVC Kolkata

One more dam, the Tenughat, was constructed by the Government of Jharkhand in 1978 on the Damodar River and designed primarily for industrial and municipal water supply uses as well as for irrigation through the Tenu-Bokaro Canal. Due to non-acquisition of land upto the design level, the dam is not meant to have any flood management component and has remained out of the control of the DVC. All five dams now fall under the territory of Jharkhand state and, except for Tenughat, which is under the control of Jharkhand, and the Durgapur barrage, which is controlled by West Bengal, the rest of the dams are operated by the DVC. The integrated operation of all structures upstream of the Durgapur barrage is managed by the Damodar Valley Reservoir Regulation Committee (DVRRC) which is headed by Member (River Management), and the Central Water Commission (CWC), with representatives from DVC and also from the states of West Bengal and Jharkhand. The main functions of the committee (DVRRC) are to discuss and lay down the principles for effective regulation of the reservoirs. The committee directs storage and releases from the DVC reservoirs on a day-to-day basis and distributes stored water to DVC and the Government of West Bengal for generating power, irrigation, and the industrial/domestic uses. A reservoir regulation manual prepared by CWC (2001a) is utilized for integrated regulation of the reservoirs for the principal benefits of flood management, irrigation, industrial and domestic water supply, and power generation.

3.10.1 Lower Damodar Scheme

To mitigate the flood problem and water logging of the lower part of the Lower Damodar Valley, the West Bengal Government developed a scheme known as the Lower Damodar scheme. It aimed to remove flood hazards and improve the drainage condition of a vast tract of the trans-Damodar area in the districts of Barddhaman, Hooghly and Howrah. This scheme was sanctioned in 1971. It envisaged jacketing of the Mundeswari River from Begua Hana to allow a discharge of 7,080 m^3/s of flood water. The work started but was stopped when a large number of people living between the embankments and the proposed jacket vehemently objected to it. They apprehended perpetual flooding of the area. The human problem played a vital role in this regard. Subsequently, the Ram Ballav Chakraborty Committee was set up to find an acceptable solution (Halder 1992; Bhattacharyya 2002). A new scheme was drawn up. It suggested re-sectioning of the original main Damodar channel to carry 708–849.6 m^3/s of flood water below the Begua Hana to the Rupnarayan River from Thalia, a place downstream from Amta of Howrah district. The work started but met the same fate as the earlier scheme. Ultimately a 58-vented outfall sluice was constructed during 1975–1976 (Halder 1992; Bhattacharyya 1998; Fig. 3.4) at Ulughata, near Garchumukh of Uluberia. As a result, the inflow of any appreciable quantity of floodwater in the Amta Channel was allowed proper exit to the Hooghly River. Tidal water from the Hooghly River also flows through the Ulughata sluice into the Damodar for irrigation purposes. A canal was cut between the Hooghly and the Damodar to carry excess water from the Damodar to the Hooghly and to carry tidal water from the Hooghly to the Damodar for irrigation. The Ulughata sluice was completed during 1975/1976. From the years between 1984 and 1985, however, the lower Damodar at the upstream of the sluice started acting as a feeder channel in summer months for growing Boro (summer) paddy in the region. The sluice at present is opened to allow the water of the Hooghly River at high tide. On the issue of flood mitigation, it was noted that at times, even while blocking tidal ingress in monsoon months by closing the sluice, the adjoining areas of lower Damodar could not reap any substantial relief from flood. So another scheme was drawn up to divert 849.6 m^3/s (30,000 cusec) of flood water entering the present Lower Damodar to the Rupnarayan by a channel connecting these two rivers. After studying all relevant geo-physical data, this channel alignment was finalized and excavation started and completed by the year 2005–2006. The channel takes off at a place about 50 km upstream of the Ulughata Sluice and joins the Rupnarayan at a place called Baxi. Incidentally, there was already a drainage channel at this place. The channel from the lower Damodar was routed through this channel after some alteration (personal communication with Chandan Ray Jan 25, 2009). The last control structure is the indigenous cross dykes or dams at Rangamatia, locally known as the Rangamatia dykes. The main purpose of these dykes is to divert the flow coming from the Durgapur barrage.

River training is ongoing in the Damodar River. Processes such as closing of the Jujuti sluice by sand bags and spill channels and remodeling of the left bank embankment by boulder pitching continue. In many places flow of the Damodar is obstructed by sand bags. Temporary bridges have been constructed in order to take sand from riverbed sand quarries. Thus the Lower Damodar, as a result of human interference to the river system through longitudinal and transverse dykes, has now become a controlled river with little natural behavior left (Fig. 2.1, Plate 2.1). The Lower Damodar has transformed from a natural channel to a "reservoir channel" (Bhattacharyya 2002, 2008a).

3.11 Impacts of Lateral Control Structures

Culturally defined, the Lower Damodar, with a multitude of control structures, now demands reasoned and exemplified answers to the following questions:

i. What are the hydro-geomorphological consequences of control structures?
ii. What is the socio-economic relevance of such control measures on the adjacent riparian tract and on the riverbed itself?

When local landlords decided to construct embankments, their decisions were influenced by immediate gain i.e., to protect the riparian tract from flood hazards. The side effects of such measures and wider physical consequences were never considered. The Environmental Impact Assessment (EIA) movement was far ahead in the future when the TVA was conceptualized in 1933 and when the DVC followed the TVA model in 1948. A series of reservoirs and barrages have come up as a consequence of planning decisions taken by engineers, planners and politicians to tame the Damodar but no attempt has been taken yet either by the DVC itself or by any other non-government agency to analyze the physical consequences of such control measures in a systematic manner. This project attempts to fill the gap while acknowledging that, for such impact analysis, not only is an inter-disciplinary approach desirable but teamwork is a necessary pre-requisite.

In the previous section control measures in the Lower Damodar were treated as effect and flood was considered the cause. In this section and in the following chapter control measures are treated as causes behind consequent hydro-geomorphic changes in the riverbed and in the adjacent riparian tract; in other words, the very status of control structure has changed from "effect" to "cause". While acknowledging that the impacts of embankments cannot be severed from those of reservoirs or dams, they have been separated for the convenience of discussion. This section discusses the impacts of lateral control structures and Chapter 4 examines the impact of dams.

In river training programs, quantified data on hydro-geomorphological parameters of the river are of paramount importance but socio-economic demands of the communities are prioritized in planning programs. Similarly to examine the hydro-geomorphological consequences of control measures, a set of quantified data is required which helps a researcher take a much desirable nomothetic method. In the case of the river under consideration, the Lower Damodar, quantified data on the embankments are available partly. Mostly qualified archival data have been used. So, the nomothetic method has been selected partly for reviewing the impacts of embankments on selected hydro-geomorphological conditions. In the next chapter where the impacts of transverse control structures have been examined and quantified data are available, a nomothetic method has been selected. Because of this particular methodological problem, the impact of transverse control structures has been treated in a separate chapter. Following King (1967) it may be said that the method of analysis is inductive too. It is most probably justifiable if it can be stated that a historical method has been applied, as the database is historical database.

During floods, like any other river, the Damodar used to cross its normal boundary in pre-embankment days. Part of the valley is still inundated in its unconfined sector and when embankments are breached or over-topped the river is extended. This extension of the river during floods needs to be considered when dealing with the spatial scale of inquiry. For impact analysis of the embankments, the total time span is 155 years i.e., from 1852 to 2007.

It is already mentioned above that the database is mostly historical. Qualified data from old maps, government reports and records have been generated. With this passive data, active field data have been used. Techniques adopted are interpretation of historical data and field survey technique. Old maps, as the basic tools, have also been consulted.

3.12 Impacts of Embankments

An embankment is a cultural feature, which becomes a viable component of a historically conditioned geomorphic landscape. How an embankment disrupts the physical process is discussed below. In the course of discussion the area outside the embankments has also been ventured on to strengthen some of the arguments.

3.12.1 Rising Riverbed

Like any other embankment, the Lower Damodar embankments have interfered with the physical process of sediment transfer and deposition. The Damodar bed load is rich in sands as it flows through a quartz-rich gneissic terrain in its upstream sector and sandstone-rich Gondwana sedimentaries in the lower reach of the upstream sector. "It is very hard to measure the bed load, or even to estimate it very closely" (Morisawa 1968, p. 46). But from the bed load characteristics it can be inferred that in the pre-embankment days the river became a wide shallow river with braided channels. As the river was extremely floodable, sizable portions of the bed load used to be deposited in the immediate flood plain during floods. In the post-embankment phase, flood discharge of the wide and braided Damodar is unable to spill and deposition takes place on the riverbed itself. The most probable consequence, therefore, is the gradual rising of the riverbed. Guliemini, an Italian Engineer, stated in a report by Goodwyn (1854) that a river is deepened due to restriction but where the bed is wide and divided into branches, its bottom will be raised. This assertion is applicable to the Damodar. The river cannot be kept in a state of regime, neither can it be deepened owing to the sandy and unstable nature of its bed (Bannerjee 1943). The 1854 map of Dickens shows the Damodar with a large number of sand bars. R.A. Marston and others have similar observations on the Ain River, France, where embankments prevent lateral reworking of flood-plain alluvium and sediments are stored within a channel (Marston et al. 1995).

3.12.2 Changes in Soil Composition in the Adjacent Riparian Tracts

In the report of the Embankment Committee of 1846, there are some remarks on the produce of the land outside and within embankments. Landlords had a feeling that land protected by embankments were deprived of the fertilizing effects of the Damodar floods, whereas in the unprotected tract, in addition to the usual varieties of rice, mulberry, sugarcane, brinjal, Bengal hemp (*Crotolaria-juncca*), *chorchorn-capsularis* (cultivated for its fibre), *Eeschynomine connbina* etc., could be raised. About 32.2 km below Barddhaman, rice was the only crop within embankments whereas outside the embankment Arum, Crotolaria juncca and cotton could be cultivated (Sage et al. 1846). Embankments provide full protection up to a certain stage and they may be breached or over-topped or collapsed due to piping action near the toe of embankment (Ward 1978). In the historical past, long before the construction of reservoirs, the Lower Damodar breached its embankments in 1770, 1787, 1789, 1823, 1835, 1840, and 1845. At least 25 breaches occurred in 1847, 14 in 1849, 56 in 1850, 45 in 1852 and 28 in 1854 (O'Mally and Chakravarti 1912; Bhattacharyya 1998, 1999–2000a). Although these breaches are generally interpreted as natural consequences of unusual floods, it is not unlikely that these were secret breaches made by the villagers for irrigation purposes. The common people used to believe that had there been no embankments, river water would have had free ingress in the rice land and the adjacent riparian tract would have benefited from deposits of the Damodar silt (Sage et al. 1846). From the above discussion one has to conclude that soil composition in the tract protected by embankments changed due to entrainment of sediments in the riverbed and lack of annual replenishment in the adjacent tract. Additional deposits of sediments on the riverbed ultimately become socio-economically significant (Bhattacharyya 1998, 1999–2000a).

3.13 Consequences of the Removal of the Right Bank Embankment

Before the flood season of 1959, a full extent of 32.19 km of the right bank embankments were removed in order to control Damodar floods and for the safety of the continuous line of left bank embankments. In the following sections, the situations in the embankment pre-removal and post-removal periods will be compared.

3.13.1 Changes in Fertility Status on the Right Bank

Prior to the removal of the right bank embankment it was reported that 762 villages with a total of 619.13 km^2 would be vulnerable to floods if the embankments were removed. Of these, 64.95 km^2 were unculturable lands. But approximately 35.30 km^2 of uncultivated land would be benefited by flood-borne sediments and 222.71 km^2 of cultivable lands would be injured, i.e., as a whole, only 40% of the land would be rendered more or less unfit for cultivation (Young 1861; Bhattacharyya 1998, 1999–2000a). Removal of these right bank embankments initially created problems for adjacent villages. Loss due to periodic inundation of an appreciable amount of paddy land was assessed at ₹5 million. This was calculated on the basis of price behavior prevailing in 1951 (DVC 1995). Such periodic floods, on the other hand, resulted in the deposition of silt which enriched agricultural lands facilitating production of splendid crops of rabi (winter crops, harvested in spring) and thus compensated for the loss of summer paddy crops (Sengupta 1951). Thus, ultimately, cultivators benefited from the removal of the right bank embankments (Bhattacharyya 1998, 1999–2000a).

3.13.2 Changing Cross Profile

The right bank embankments were demolished in 1859. The DVC (1957b, Vol. II) report states that this arrangement gave relief for a certain number of years. The removal of the right bank embankments led to an enormous increase in the cross section of flow and a corresponding lowering of the level of high flow. But at the same time the velocity of flow was considerably reduced, thereby increasing the rate of silt deposition in the bed and raising its level more rapidly than before. This issue raised some controversy at that time.

3.13.3 An Increase in Cross Section

The cross sections of the channel at different points increased enormously between 1881 and 1943 (Fig. 3.6) and there was a corresponding lowering of the level of high flow. In some places the cross sections are characterized by pronounced flood plains between embankments or between embankments and river levees. When these get inundated, velocities on the flood plains are lower than those in the thalweg itself. This causes the effective cross-sectional area in the river to become smaller than the actual geometrical cross section (CWC Interim Report 1983). The width of the river has increased considerably in many places; it has narrowed in some places and a few areas remain constant (Table 3.7).

3.13.4 Opening Up of Hana or Spill Channels on the Right Bank

A chain of *hanas*, or spill channels, opened up by breaching natural levees on the right bank. These breaches or spill channels are locally known as hana. A chain

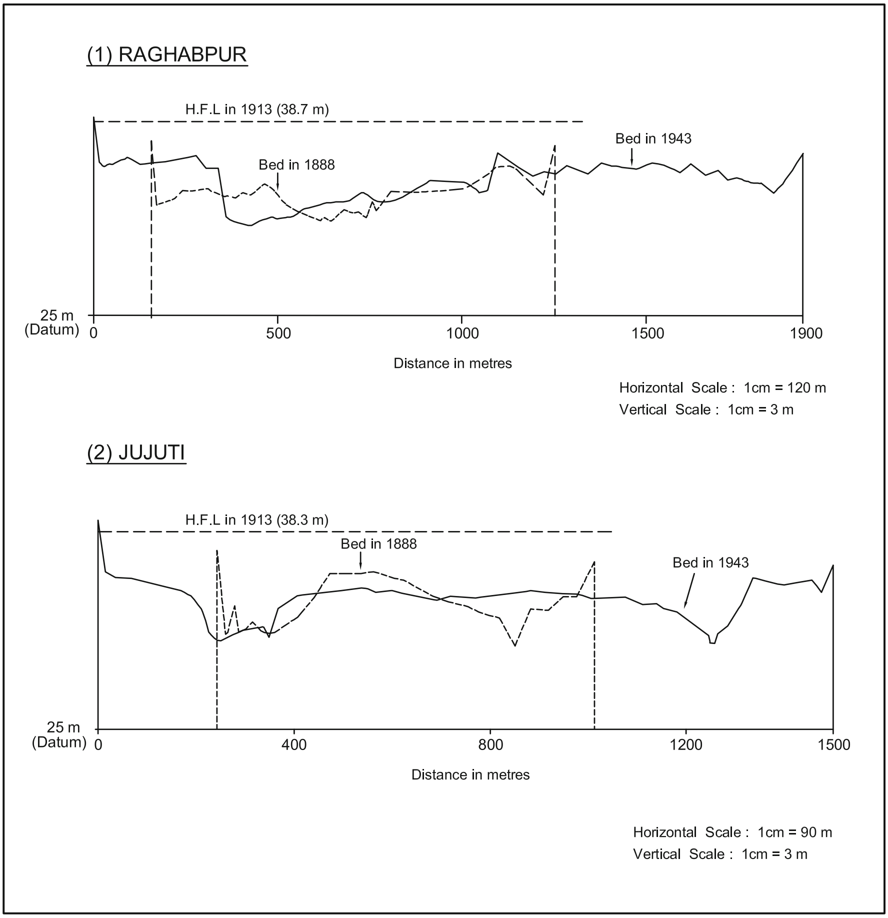

Fig. 3.6 Cross sections of Damodar River at selected sites. Source: After I & WD, WB

of spill channels serves as a spillway for flood waters of the Lower Damodar to overflow into the low land through which run the Debkhal and its ramifications. Entire low-lying areas become a sheet of yellow water moving eastward and then southwards during the rainy season. Thus the flood water, unable to pass through the restricted channel of the main river, finds its way into the Deb khal (Bose 1948; Fig. 3.7). In 1956 maximum discharge at Rhondia (at 24 h) on 26th September was 8,694 m^3/s and maximum discharge at Jamalpur on 27th September was 3,002 m^3/s. On the same day maximum discharge was 7,307 m^3/s at Muchi hana and 708 m^3/s at Champadanga. Thus, it appears that a discharge of about 5,692 m^3/s passed over the right bank in the reach between Silna and Jamalpur (DVC 1978). Due to such spilling over the right bank, the left bank embankments were not breached during major floods of 1959 and 1978 (Bhattacharyya 1998, 1999–2000a).

Table 3.7 Width of the Damodar River at different places between 1881 and 1943 (in meters)

Stations	1888	1913	1918	1943
Raghabpore	1,097.28	2,072.64	2,072.64	1,928.34
Jujuti	987.552	1,298.45	1,310.64	1,524
Edilpur	1,248.68	1,245.41	1,245.41	1,127.76
Becharhat	1,126.82	1,164.92	1,280.16	1,173.48
Manikhati	853.44	853.44	835.15	1,066.8
Salalpur	987.552	966.22	987.55	920.50
Palla	897.62	882.40	897.65	893.07
Serangpur	615.69	621.79	621.79	502.92
Jamalpur	396.24	345.34	345.34	403.56
Dhapdhara	386.24	384.05	396.24	365.76

Source: Sen (1962).

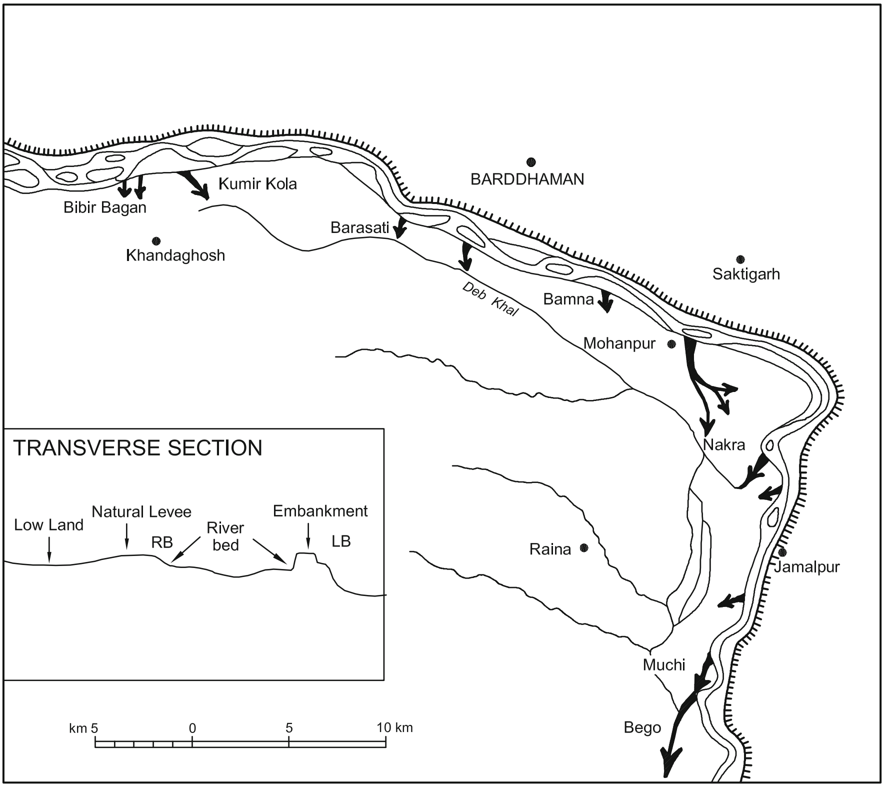

Fig. 3.7 Hana or spill channel on the Damodar River. Source: Bhattacharyya (1998, 1999–2000a)

This spilling over the right bank has decreased now as the river has formed a natural levee and most of the spill channels on the right bank are either closed or take lesser amount of water and leave sediments to be deposited within the channel itself. As a consequence, the riverbed and the flood level have risen considerably. Previously the Damodar used to open up flood channels towards the north east or south east. As the left bank is protected by embankment, spill channels in the historical past have opened up on the right side.

3.13.4.1 Origin of the Begua and the Muchi Hana and Deterioration of the Amta Channel

A natural flood channel known as Begua hana was probably opened up in 1865. The river below Harogobindapur had already formed an acute bend that affected the left banks embankments. By 1856, a well-defined spill channel had formed on the right bank of the Damodar to relieve the pressure on the left bank embankments. In an old map, mentioned in the DVC report of 1957a (Vol. I), it appears that in 1857 a dyke was put up across the Damodar below this spill channel. This dyke probably helped in the development of the Begua hana. Later on a cut-off known as the Muchi-hana or khal was affected by joining the neck of the loop formed by the Begua hana at Muidipur under the Jamalpur police station. Locals believe that this artificial measure was taken to protect the settlements and the railway line on the left bank. Floods below the Muchi spill channel are now attributed to this artificially cut spill channel (Ghosh 1993; Bhattacharyya 1998, 1999–2000a, Fig. 3.8). Bird (1980) observes similar phenomenon in the Lang Lang River, Victoria, Australia, where an artificial neck cut-off has made for straightening the channel.

Around 1865 a great Begua breach occurred on the Lower Damodar and scoured out a channel parallel to the main Damodar known as the Kanki that eventually joins the Mundeswari River (DVC 1957a, Vol. 1; Fig. 3.8). The combined stream falls into the Rupnarayan River. At this bifurcation point, formation of a high sand bank completely shuts off the flow of water into the Damodar known as the Amta channel below this bifurcation point. A newly scoured bed of the Muchi-hana is lower than the sand filled bed of the main Damodar (Bose 1948; DVC 1957a, V-1), which is now used for cultivation in the non-monsoon period.

The Amta channel i.e., the lowermost part of the Lower Damodar, gets water through the Begua hana and this channel. It has shrunk perceptively in size and volume due to reduced discharge as the downstream discharge in the lower reaches below bifurcation point into the Kanki-Mundeswari and the Amta channel is in the 4:1 ratio (DVC 1995; Bhattacharyya 1999–2000a). The Kanki-Mundeswari channel hydrologically formed a much shorter route than the Amta channel route via Uluberia. Under these circumstances the old Damodar i.e., the Amta channel, gradually deteriorated not only because of its longer hydraulic length but also because of its absence of spill area due to embankments on both sides, as well as gradual encroachment on the riverbed (DVC 1995; Bhattacharyya 1999–2000a). Bankfull capacity of the Mundeswari is hardly 2,832 m^3/s, and the Amta channel has silted up so much that hardly 5–10% of the discharge passes through it at present. The

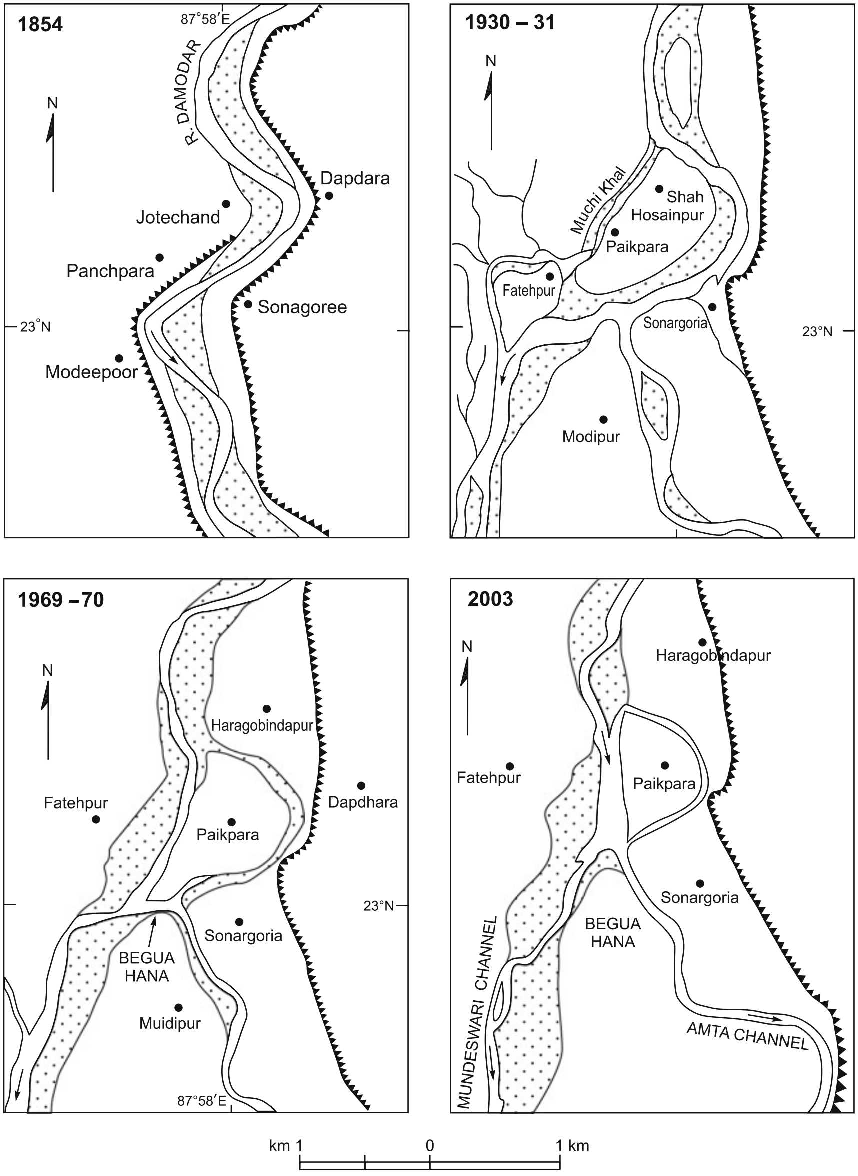

Fig. 3.8 Opening of Begua or Muchi hana on the Damodar River. Source: Bhattacharyya (1998, 1999–2000a)

actual carrying capacity of the Amta channel is only 849 m^3/s even after revival through the Lower Damodar areas improvement scheme (CWC 2001a). From 2003 LISS-3 scenes taken by an IRS-ID satellite (Fig. 3.8) it is evident that a small sand-bar has been formed in the Mundeswari River, so that, during low water periods, the

Amta channel gets more water than the volume flowing through the Mundeswari River. At present, the downstream discharge between the Mundeswari and Amta channel is divided in the ratio 7:3.

3.14 Impact of the Left Bank Embankment

To save the town of Barddhaman, the Grand Trunk Road, and the railway line from flood havoc,, the left bank embankment was not only strengthened but disjointed portions were connected and a second line of embankments was constructed in places. The consequences often became hazardous. Changes have been observed in the regional slope.

3.14.1 Drainage Congestion

The district of Barddhaman is bounded by the Ajay to the north and the Damodar to the south. The watershed is ill-defined particularly in the east. The Khari (Khuria) and Banka drain this area (Fig. 2.3). Previously much of the Damodar flood water used to pass through these two rivers, but roads, railways and embankments have severed these rivers from the mother stream. As a natural consequence both the rivers have deteriorated and have become flood-prone. Secondly, the water that used to flow into the Damodar now creates water-logging in this low inter-stream area. This drainage congestion has been reported by Haig (1873), by Biswas and Bardhan (1975) and by Akhtar et al. (2010). Water-logging is conducive to breeding of mosquitoes and the region for decades has suffered from Barddhaman fever, a kind of malaria. Its water-logged condition affected agriculture and the region had to face fever, famine and depopulation between 1850 and 1925 (Biswas and Bardhan 1975). Although drainage conditions have improved in recent years, a few pockets still suffer from drainage congestion and its consequences. The area discussed above falls outside the study area but occasional trespassing becomes necessary to fortify some of the arguments against the unplanned chaining of the river. In the Kaliaghai River of West Bengal, riparian communities applied indigenous technological innovations and helped in the functional management of seasonally waterlogged area (Bhattacharyya 1994).

3.14.2 Reversal of Slope

In earlier times the regional slope was from the Barddhaman side towards Bankura i.e., from north to south. Since the southern bank is not protected, there is continuous siltation in the flood plain of the south bank or right bank. As a consequence, the right bank flood plain has become higher and it forces the thalweg to move northward, creating pressure on the left bank embankment. This reverse slope (Fig. 3.9) is a noticeable consequence of the removal of embankments on the right and the presence of the embankment on the left. In the 1995 and 2007 floods, some of the

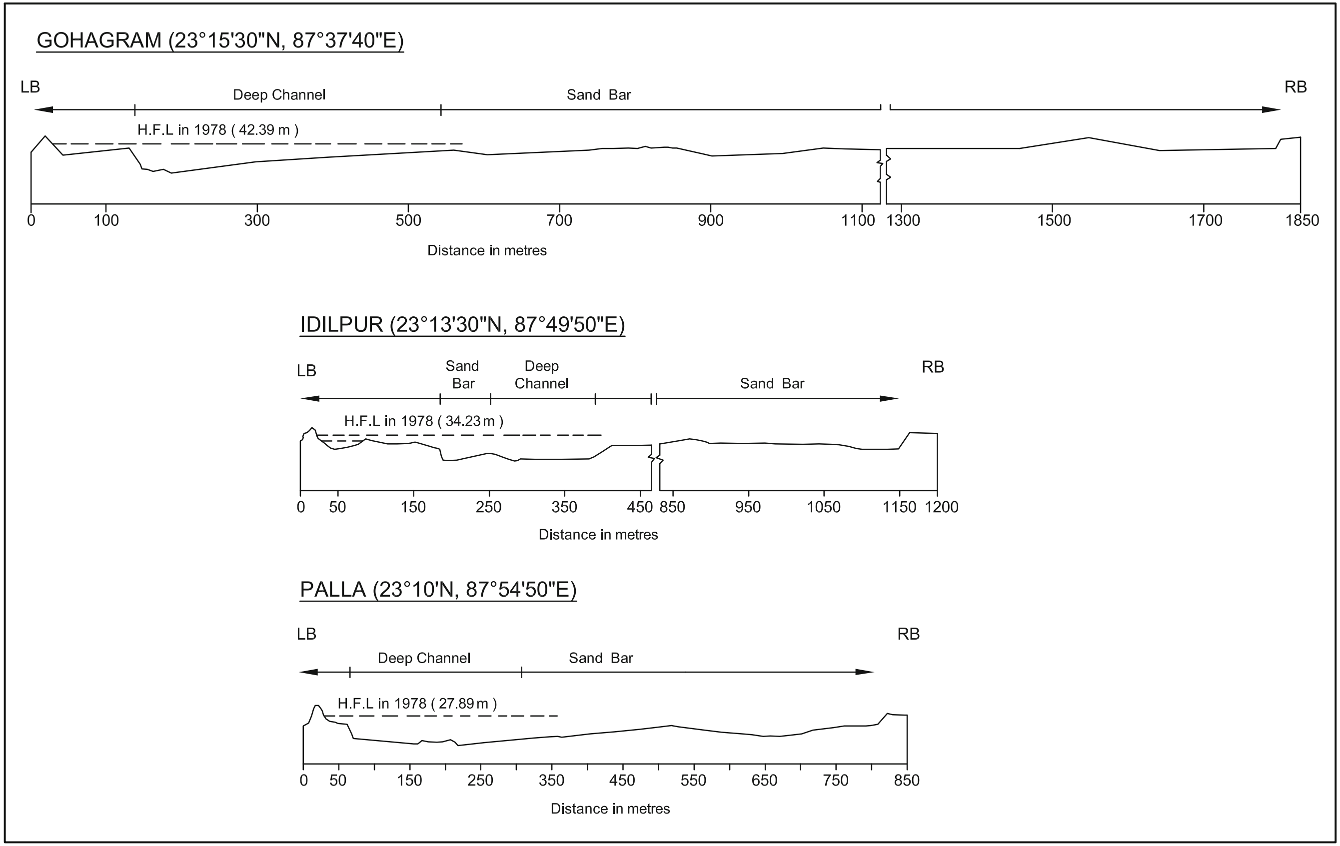

Fig. 3.9 Cross profiles of Damodar River at selected sites. Source: After I & WD, WB

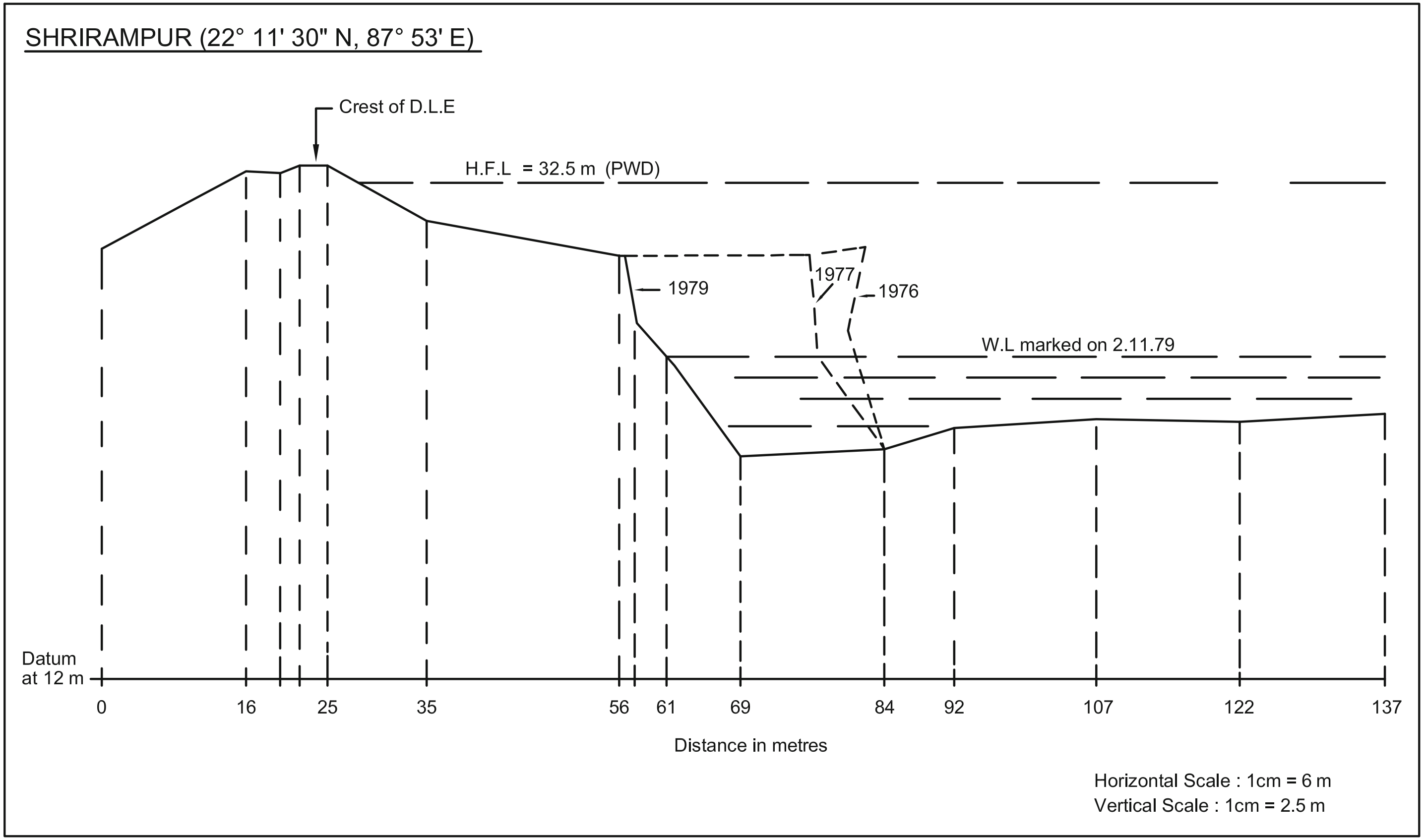

Fig. 3.10 Shifting of left bank of the Damodar River. Source: After I & WD, WB

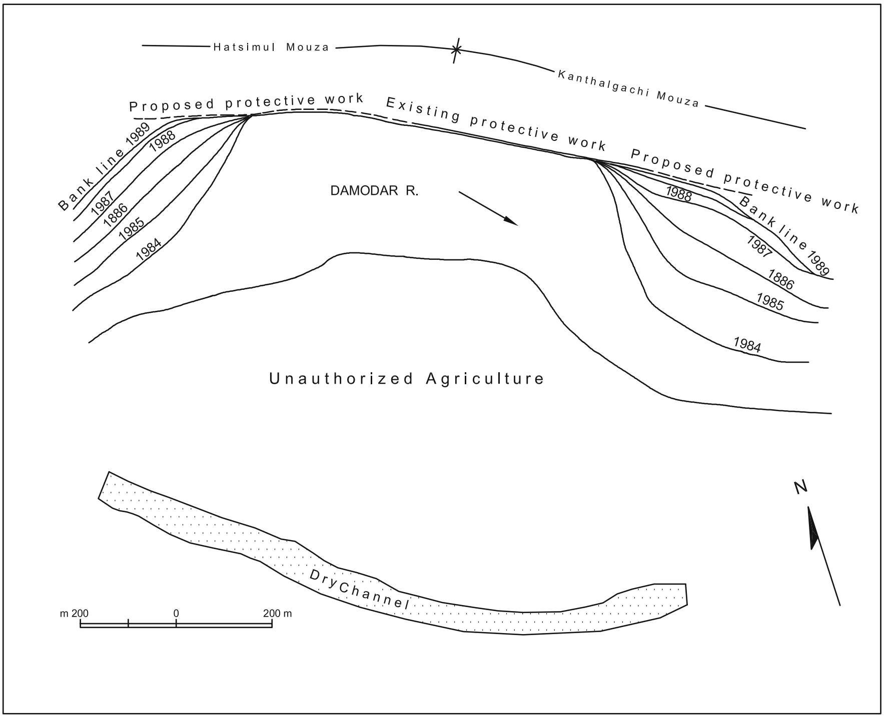

Fig. 3.11 Shifting of bankline (Hatsimul Mouza to Kanthalghachi Mouza). Source: After I & WD, WB

abandoned flood channels on the left were re-activated and the left bank embankment has breached in several places. The left bank is thus becoming vulnerable. Shifting of bank line is prevalent between Shrirampur and Kalinagar (Figs. 3.10, 3.11 and 3.12) near Palla village (Bhattacharyya 1999–2000a). Channel migration in the middle Ganga (Philip et al. 1989), migrations of bank lines and consequent problems in the Lower Ganga in India and in the Brahmaputra in Bangladesh have been noted by Bandyopadhyay (1994, 2002) and Goswami (1988) and Thorne et al. (1993) respectively. The shfting trend and changing geomorphology of the Kosi River has been studied by Ansari (1987) and Bose et al. (2009).

3.15 Summary

The Lower Damodar has always been a flood-prone river. It has changed its main flow several times in the historical past and its shifting courses can be identified if we collate archival maps. Recorded flood history, however, dates back only from 1730. Since 1730, floods of different magnitudes have occurred every 8–10 years.

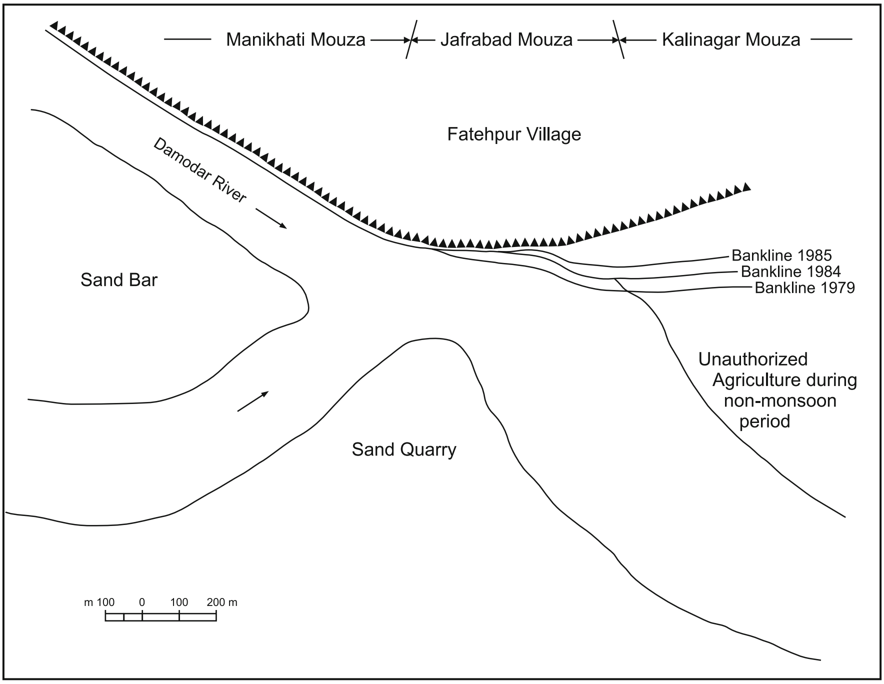

Fig. 3.12 Shifting of bankline (Manikhati Mouza to Kalinagar Mouza). Source: After I & WD, WB

In the twentieth century, the September flood of 1978 is interpreted as the greatest disaster in South Bengal within a 100-year period.

Embankments were obviously the first control measures on the Lower Damodar. These were constructed by local landlords but the need for embankments was extensively examined during the colonial regime. The right bank embankments were removed and the left bank embankments were raised and fortified. This resulted in a gradual rise of the riverbed, changes in soil characteristics in the adjacent riparian tract, widening of the river between embankments, and opening of spill channels on the unprotected right bank. Other consequences include opening of the Begua and the Muchi spill channels on the right, drainage diversion through the Kanki-Mundeswari, deterioration of the Amta channel, drainage congestion to the north of the left bank embankment resulting in increased incidence of Barddhaman fever, shifting of the thalweg towards Barddhaman side due to reversal of slope, and shifting of bank lines on the left bank. The left bank embankments have also been provided with many sluices, the Jujuti sluice being one of them, but due to lack of maintenance some of the sluices do not operate properly. Canals were dug to divert excess water from the river and to revive some of the decaying distributaries of the Damodar through water transfer from the canal to the river. The Eden canal was constructed for this purpose in 1881.

The most important control structures on the Lower Damodar are the Maithon and the Panchet reservoirs which are outcomes of the DVC and began functioning properly from 1957 and 1959 respectively. Despite several control measures taken by the DVC, the lowermost part of the Lower Damodar, the Amta channel, is deteriorating. To address this problem, a 58-vented outfall sluice was constructed at Ulughata in 1975–1976 as a program of the Lower Damodar Scheme. The last mention-worthy control structure is the Rangamatia cross dyke, locally referred to as the Rangamatia dam at Rangamatia sandbar.

The River control process is an ongoing process that includes strengthening of embankments, closure of spill channels, and drainage diversion as components. But the process itself is an anthropogenic process which has given rise to several cultural features such as embankments, weirs, sluices, barrage and reservoirs. These cultural features are the indicators for identifying the characteristics of the Lower Damodar. The stretch between the Maithon and Panchet reservoirs to the Falta outfall is thus culturally defined. This places a particular responsibility on us to take a long-term and holistic view of the entire river system and deal with it in a way that ensures its ecological health while meeting the diverse needs of people.

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Chapter 4
The Reservoired Lower Damodar River: A Hydro-Geomorphic Perspective

Abstract Rivers respond to anthropogenic activities through morphological and hydrological adjustments in the channel. This chapter addresses the hydromorphological consequences of the control structures on the Damodar River. Dams have altered the flow regime, channel characteristics and the sediment supply of the river. Under natural flow conditions, on an average, 12 days per year experienced a flow above 2,265.6 m^3/s. This has decreased to 4 days under artificial conditions. Monsoon streamflow has been reduced, but non-monsoon flow has increased albeit with a very high variability in the post-dam period. The R.I. of the bankfull stage, a flow of 7,080 m^3/s in the pre-dam period, increased from 2 to 14 years in the post-dam period. The magnitude of the design flood from Maithon and Panchet reservoirs has been reduced by about 56%. During the non-monsoon period canal discharge in most cases exceeds the river discharge. The low volume of water released downstream during dry months virtually transforms this section into a sandy waste whereas the high discharge released during monsoon months converts the section to a vigorous flowing channel. Although some sediment is trapped in the reservoirs, a million tons of sediment nevertheless pours into the river from the uncontrolled stretch. Capacity of the river to transport this sediment has been reduced due to the reduction of flood peaks. A chain of sandbars has emerged within the riverbed below the control structures. The channel deposits in the study area support agriculture and most of the channel bars have been settled and are now used as a resource base, mostly by Bangladeshi refugees.

Keywords Anthropogenic · Dams · Flow-regime · Hydromorphological · Monsoon streamflow · Refugees · Reservoirs · Sandbars · Sediment

4.1 Damodar: A "Reservoir Channel"

Any river unaffected by human controls attains a state of equilibrium due to the complex interplay of many interdependent variables such as discharge, sediment, and channel characteristics. A natural river system is an open system in dynamic equilibrium in which dependent variables such as river channel slope, gradient, and

K. Bhattacharyya, *The Lower Damodar River, India*, Advances in Asian Human-Environmental Research 3, DOI 10.1007/978-94-007-0467-1_4,

planform get adjusted to the inputs of water discharge and sediment load. If changes occur in any of these inputs, the system responds immediately by adjusting its morphology. River control measures disturb this state of equilibrium (Bhattacharyya 1998). In the Damodar River, human modifications of the natural system have altered the flow regime, flood behavior, and the sediment supply of the river. Fluvial systems have been affected by the construction of control structures such as barrages and dams. In this study, historic streamflow, rainfall and sediment data have been collected and analyzed in order to document these changes.

Dams, barrages, and weirs normally belong to the category of transverse control structures with which the present study is concerned. Regulators, sluices, and canals are also included in this category since discharge and sedimentation below these points are also related to these control structures. Typically, the impacts of transverse control structures cannot be isolated from those due to lateral control structures. Some of the noticeable changes, however, were recorded only after dam closure. Therefore, it may be safely assumed that these changes followed the construction of the major control structures. In the following paragraphs, the impacts of transverse control structures, focusing primarily on dams are examined.

The impacts of dams on the flow regime, sediment and channel characteristics of the Damodar River during the period between 1933 and 2007 are assessed. Further topics of discussion will include changes in suspended sediment concentration, silting of reservoirs, changes in bed slope, change in the sinuosity index of the Lower Damodar thalweg, change in channel characteristics, the stabilization of bars after dam closure, and shifting bank lines and bank erosion. Finally, the present condition of the Jamalpur regulator, the Jujuti sluice, the Eden canal and the Ulughata sluice will be reviewed.

For a comparative analysis of the changes in the river regime of the Lower Damodar River, data from 1933 to 2007 have been divided into two periods, the pre-dam period between 1933 and 1956, and the post-dam period between 1959 and 2007.

4.2 Impacts of Dams: Changing Flow Regime

One of the important variables in a fluvial system is river discharge (Schumm 1977). Both base flow and the episodic flows are most important in maintaining a fluvial landscape. The base flow, average flow and peak flow in the pre-dam and post-dam periods are analyzed here based on hydrological observation (Appendix B) to assess the effects of the major control structures on the lower Damodar River.

4.2.1 Daily, Monthly Mean, and Annual Flow Characteristics

In the 10-year record (1940–1949) of the Damodar streamflow at Rhondia, about 62.6% of the days experienced a flow of less than 2,83.2 m^3/s (10,000 cusec) and 3.4% experienced a flow above 2,265.6 m^3/s (80,000 cusec). During the post-dam period (1993–2007) (Table 4.1), about 71.92% of the days experienced a flow less

Table 4.1 Frequency of daily streamflow of the lower Damodar at Rhondia in pre-dam (1940–1949) and post-dam (1993–2007) periods

	Percentage of total number of days		
Class unit in m^3/s	Pre-dam	Post-dam	Percentage change
Below 283.2	62.60	71.92	+14.89
283.2–566.4	7.00	9.00	+28.57
566.4–849.6	5.30	4.90	–7.55
849.6–1132.8	3.70	2.50	–32.43
1,132.8–1,416	2.80	1.60	–42.86
1,416–1,699.2	2.20	1.23	–44.09
1,699.2–1,982.4	1.50	0.75	–50
1,982.4–2,265.6	1.50	0.30	–80
Above 2,265.6	3.44	1.20	–65.12
Percentage of no flow days	9.96	6.5	–34.74
	100%	100%	

Total number of days in pre-dam period = 3,653. Total number of no flow days = 364. Total number of days in post-dam period = 5,425. Total number of no flow days = 367. Data not available = 53 days.
Data Source: Appendix B

than 2,83.2 m^3/s, a percentage increase of about +14.89, whereas only 1% of the days experienced a flow above 2,265.6 m^3/s, a percentage change of about –65.12. Under natural conditions mean daily flow fell below 2,83.2 m^3/s 229 days per year increasing slightly to 261 days between 1993 and 2007 whereas, under natural conditions, 12 days on average in a year experienced a flow above 2,265.6 m^3/s which has decreased to 5 days under controlled conditions. The total number of no-flow days was 364 i.e. 9.96% in the pre-dam period, whereas no-flow days in the post-dam period are 367 which is 6.76%. In the post-dam period daily streamflow of 566.4–849.6 m^3/s (20,000–30,000 cusec) to above 2,265.6 m^3/s shows a negative trend (Table 4.1). The representative daily average streamflow for the Damodar at Rhondia is 381 m^3/s in the pre-dam and 245 m^3/s in the post-dam period (Fig. 4.1).

During the pre-dam period (1953–1955), about 78.21% of days experienced a flow less than 566.4 m^3/s at the Damodar Bridge site but in the post-dam period (1983–1990) about 68.15% of the days experienced a similar flow (Table 4.2) indicating a relatively wetter condition in the post-dam period. A release from dams throughout the year provides a median of about 137.71 m^3/s with a mode of 103.91 m^3/s for the year 1975. However, the median and modal values for 1955 were 91.96 and 75.50 m^3/s respectively (Sen 1978).

The average daily streamflow for a given year is computed by taking the average streamflow data during each day calculated from hourly streamflow, adding these for 365 consecutive days, and dividing the total by 365 or by the total number of days of data availability. To get a representative daily streamflow, these annual figures for a number of years have been averaged. Similarly, monthly and annual total streamflow

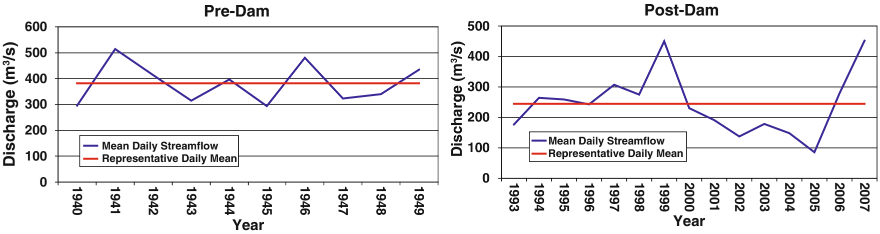

Fig. 4.1 Characteristics of daily discharge and representative daily average discharge of the lower Damodar River at Rhondia in pre-dam (1940–1949) and post-dam (1993–2007) periods
The average daily discharge for a given year is computed by taking the average discharge during each day calculated from hourly discharge and adding these for 365 consecutive days and dividing the total by 365 or by total number of days of data availability. To get a representative daily discharge these annual figures for a number of years have been averaged. Similarly monthly and annual peak discharges were averaged. Frequency of daily discharge and the percentage change has been computed.

Table 4.2 Frequency of monsoon streamflow of the lower Damodar River at Damodar bridge site in pre-dam (1953–1955) and post-dam (1983–1990) periods

Pre dam	
Total number of days – 459	
Class unit (m^3/s)	Percentage to total number of days
Below 566.4	78.20
566.4–1,132.8	15.60
1,132.8–1,699.2	3.70
1,699.2–2,265.6	1.18
Above 2,265.6	1.31
Post dam	
Total number of days – 1,193	
Class unit (m^3/s)	Percentage to total number of days
Below 566.4	68.15
566.4–1,132.8	16.26
1,132.8–1,699.2	7.96
1,699.2–2,265.6	3.70
Above 2,265.6	3.93

Data Source: Hydraulic Data Division, DVC, Maithon.

were averaged. Frequency of daily streamflow, as well as the percentage change, has also been computed.

Time series analysis, showing the variation of streamflow of the Damodar at Rhondia in the pre and post-dam periods, is shown in Fig. 4.2.

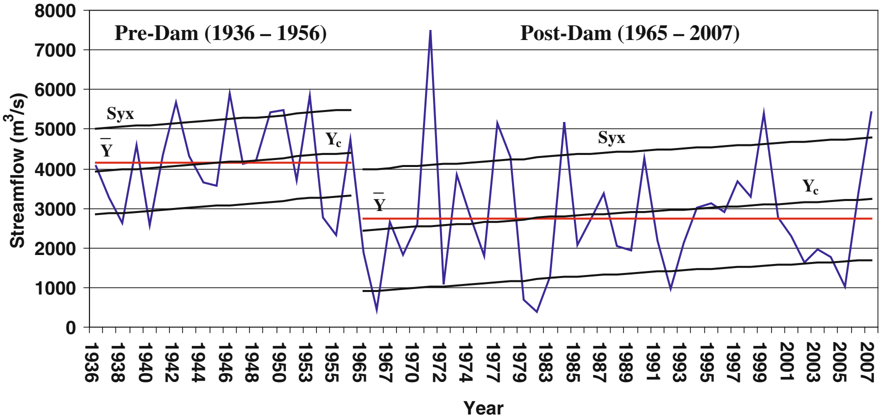

Fig. 4.2 Trend of mean annual discharge of the lower Damodar River at Rhondia in pre-dam (1936–1956) and post-dam (1965–2007) periods
Yc = 4161.5 + {(−24.26)x}, Syx = 1, 084 m3⁄s, Average Streamflow (Y) = 4, 162 m3⁄s (pre-dam)
Yc = 273.97 + {(−66.73)x}, Syx = 1, 533 m3⁄s, Average Streamflow (Y) = 2, 737 m3⁄s (post-dam)
Data Source: Refer to Appendix B

There,

$$Yc = a + bx$$

where

Yc = estimated streamflow
a = value of y where x = 0
b = rate of change of y per unit of x,
x = deviation of the actual streamflow from the mean streamflow

The trend lines are Yc = 4161.5 + {(−24.26) x} for the pre-dam period and Yc = 2736.97 + {(−66.73) x}, for the post-dam period. It is expected that the discharge will vary on either side of the trend line. In both cases the trend lines show a decrease. From Fig. 4.2 it is clear that discharge was increased after 1935 due to the depression after the First World War when work in most of the industries had stopped reducing the demand for water in the industrial sector and resulting in an enhanced average streamflow. The decreasing trend in the pre-dam period was due to extraction of water by industries in the Damodar valley. The range of fluctuation has increased during the post-dam period, as shown by the standard error of estimate or Syx which is 1,084 m^3/s for the pre-dam period increasing to 1,544 m ^{3}/s for the post-dam period. An increase in the range of fluctuation in that period indicates that the release below the Durgapur barrage corresponds to the demand of water for canal consumption and uncertainty in the amount of rainfall. It is also true that

Table 4.3 Streamflow characteristics of Damodar River at Rhondia in pre-dam (1934–1956) and post-dam (1959–2007) periods (% of streamflow with respect to mean annual streamflow total)

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

N = No of years, X = Average % of flow, s.d = standard deviation, c.v. = coefficient of variation. Summer – March to May, Monsoon – June to September, Autumn – October – November, Winter – December to February.

Data Source: Computed by the author based on processed data in Appendix C.

water is released downstream, not according to natural cycles, but as dictated by the region's hour-by-hour needs for irrigation and other purposes.

The discharge of the Damodar at Rhondia and at the Damodar bridge site for four climatologic seasons with respect to the total annual flow from 1934 to 2007 for Rhondia and 1953–2007 for the Damodar Bridge site is given in Tables 4.3 and 4.4. Flow at Rhondia shows a sharp contrast between the pre-dam and post-dam periods. During the summer season (March–May) the mean percentage of flow shows a significant increase from 1.40 to 5.07%, but with a large standard deviation (6.67) and very high variability (131.56) during the post-dam period. The mean autumn (October–November) discharge shows a marginal increase but with large standard deviation and variability. The same is true for the winter (December–February)

Table 4.4 Streamflow characteristics of Damodar River at Damodar bridge site in pre-dam (1953–1955) and post-dam (1969–2007) periods (% of flow with respect to mean annual streamflow total)

Period	Parameter	Summer	Monsoon	Autumn	Winter	Mean annual total (m^3/s)
Pre-dam	N	3	3	3	3	3
	X	2.81	84.25	8.68	4.26	63,193.99
	s.d	1.91	7.14	3.91	1.34	23,811.31
	c.v	67.97	8.47	45.05	31.46	37.68
Post-dam	N	27	27	27	27	27
	X	4.89	76.38	15.25	3.48	68,457.87
	s.d	3.96	13.11	10.43	2.89	37,294.81
	c.v	80.98	17.16	68.39	83.05	54.48

N = No of years, X = Average % of flow, s.d = standard deviation, c.v. = coefficient of variation. Summer – March to May, Monsoon – June to September, Autumn – October – November, Winter – December to February.

Data Source: Computed by the author based on processed data in Appendix D.

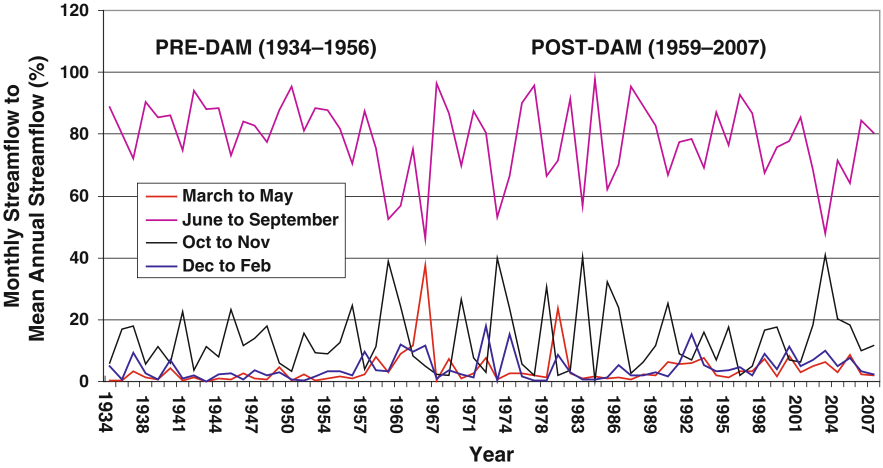

Fig. 4.3 Discharge characteristics of the lower Damodar River at Rhondia in pre-dam (1934–1956) and post-dam (1959–2007) periods (percentage of streamflow with respect to mean annual total streamflow). Data source: Appendix C

discharge. The mean monsoon discharge (June–September) shows a decrease in the post-dam period but with large standard deviation and variability as well. The total annual discharge during the pre-dam period was much higher than that in the post-dam period; deviation and variability have both increased during the post-dam period. The most important characteristic is that there has been at least a 30% decrease in average annual discharge from the pre-dam to the post-dam period and nearly a 48% increase in variability (Fig. 4.3; Appendix C).

Flow at the Damodar Bridge site shows that summer and autumn discharge has increased significantly from the pre-dam to the post-dam period while monsoon flow has decreased significantly from 84 to 76% in the post-dam period. There has been at least an 8% increase in mean annual discharge from the pre-dam to the post-dam period and nearly 31% increase in variability (Table 4.4; Appendix D). Regarding total annual streamflow, the significant increase is interestingly associated with low variability. After dam closure monsoon flow has been reduced due to control by dams. The water is released during the non-monsoon period (i.e. in summer, autumn and winter) to the Durgapur barrage from which water is diverted to canals for irrigation. Increasing demand for irrigation water has enhanced the non-monsoon flow to some extent. Thus, there is considerable augmentation of flow in the lean season mitigating the non-monsoon demand for irrigation. An irrigation system dependent on rainfall and river discharge has been replaced by fully assured irrigation through regulated release from reservoirs. Much of the surplus water that used to flow down the river is now stored in the reservoirs. The reservoir releases correspond to the actual requirements of crops and hydropower generation.

The purpose of reservoirs is to store a significant amount of surplus rainfall draining into the parent channel. The stored water is then distributed through canals

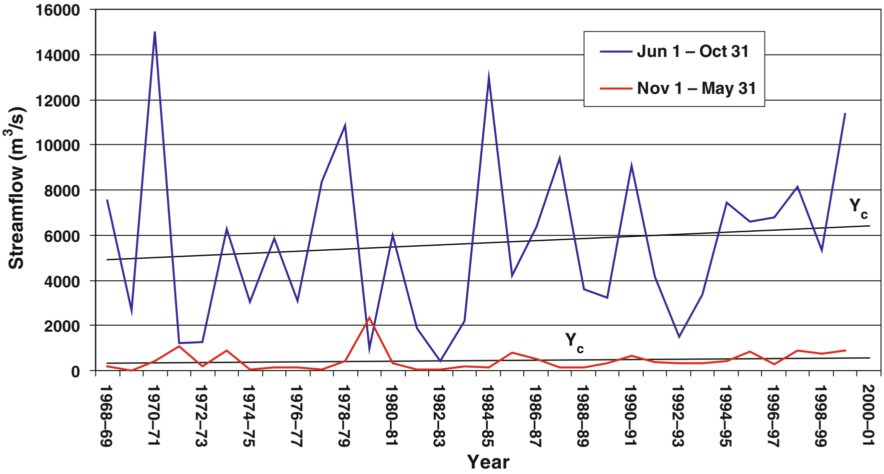

Fig. 4.4 Trend of monsoon and non-monsoon discharge of the lower Damodar River below the Durgapur Barrage (Data source: Appendix B)

whenever necessary. The magnitude of canal flow (Y) from the Durgapur barrage depends on total inflow (x) into the barrage from the Maithon and Panchet combined outflow. A linear regression model of the form $Y = a + bx$ has been worked out for different years for data extending over 12 months (Appendix E). The variables show a conformal positive relation $r = 0.81$.

A time series analysis showing variations in discharge released down the Durgapur barrage for the period extending from June to October and again from November to May has been performed. The trend lines in both periods move in a positive direction. Hence, both the monsoon and non-monsoon flows from the Durgapur barrage show an increase in discharge (Fig. 4.4). Volume of water released to flow down the Durgapur barrage and canals (left bank and right bank) are also shown diagrammatically (Fig. 4.5). During the non-monsoon period (November–May), canal discharge in most cases exceeds river discharge. Low volumes of water released into the river below the barrage during dry months virtually transform this section into a sandy waste whereas high discharge during the monsoon season converts this section to a vigorous flowing channel.

4.2.2 Changes in Peak Flow Characteristics

The presence of storage reservoirs and the barrage on the Damodar disrupts its equilibrium leading to a series of changes in the fluvial system. In such a channel water stored behind a dam and gradually released results in marked reduction in the magnitude and frequency of peak streamflow disturbing the stable channel equilibrium as well as the flow regime (Williams and Wolman 1984; Kondolf 1997; Chin et al. 2002; Magilliigan and Nislow 2001, 2005; Graf 2006; Bhattacharyya

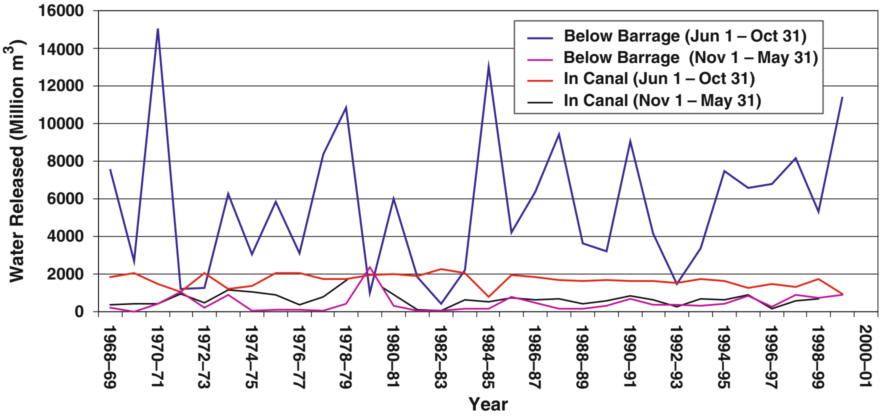

Fig. 4.5 Volume of water supplied down the Durgapur Barrage and left and right bank main canal
Irrigation potential has been drastically increased below barrage. Kharif crops are sown after the first shower of monsoon, and are harvested after the last spell of monsoon. Rabi crops are winter crops, sown in autumn and harvested in spring. Kharif irrigation was extended to 82,600 acres (3,34,274 ha) by the end of the 1999 Kharif season, against the target of 9,73,000 acres (3,93,763 ha). Rabi (winter crops harvested in spring) irrigation has been extended to 52,000 acres (21,044 ha) against the target of 55,000 acres (22,258 ha). With the popularity of Boro (paddy) cultivation due to its high yielding variety, farmers are trying to bring more and more area under Boro irrigation. As it is a summer (February to May) crop, water requirement for Boro irrigation is quite high and is dependent mainly on surface water released from the reservoirs and ground water
Data Source: Refer to Appendix E

1998, 1999–2000b, 2008; Richter et al. 2010). Similar results have been observed in numerous large watersheds around the world. For example, Dolan et al. (1974) have recorded a 60% reduction in the magnitude of the mean annual flood on the Colorado River below the Hoover Dam. William and Wolman (1984) have noted that average annual peak discharges from 21 sites from the US Geological Survey were decreased from 3 to 91% of their pre-dam values averaging about 39%. For the Damodar river, the average annual peak streamflow recorded at the Rhondia gauging site has been decreased to 57% of its pre-dam (1933–1956) value (Figs. 4.6 and 4.7). The average peak streamflow at Rhondia decreased to 3,607 m^3/s in the post-dam period (1959–2007) from the pre-dam (1933–1956) flow of 8,413 m^3/s and the Pre-Rhondia (1823–1917) flow of 11,651 m^3/s.

A time series analysis has been done on the basis of the data given in Appendix F to show the peak streamflow characteristics of the Damodar in the pre-dam and post-dam period, and is shown in Fig. 4.6. The equation for the trend line is $Y_C = a + bx$ where

Y_c = estimated streamflow
a = value of y where x = 0
b = rate of change of y per unit of x,
x = deviation of the actual streamflow from the mean streamflow

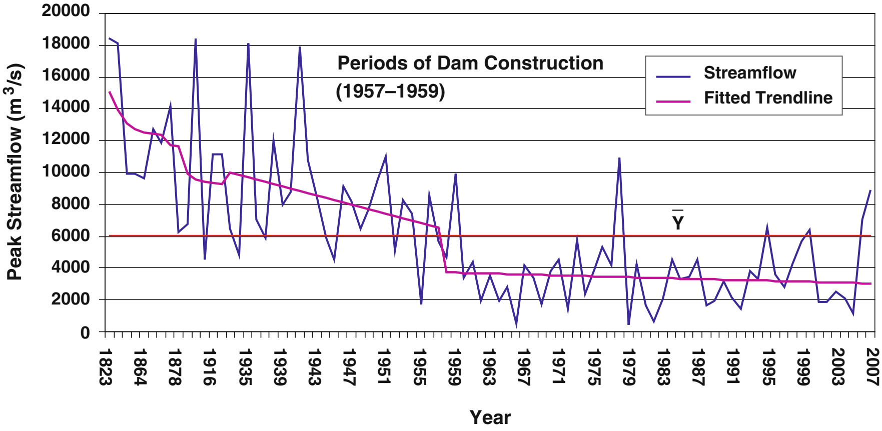

Fig. 4.6 Peak streamflow characteristics of the lower Damodar River at Raniganj (data shown before 1933) and at Rhondia (data shown from 1933 to 2007). Data Source: Refer to Appendix F

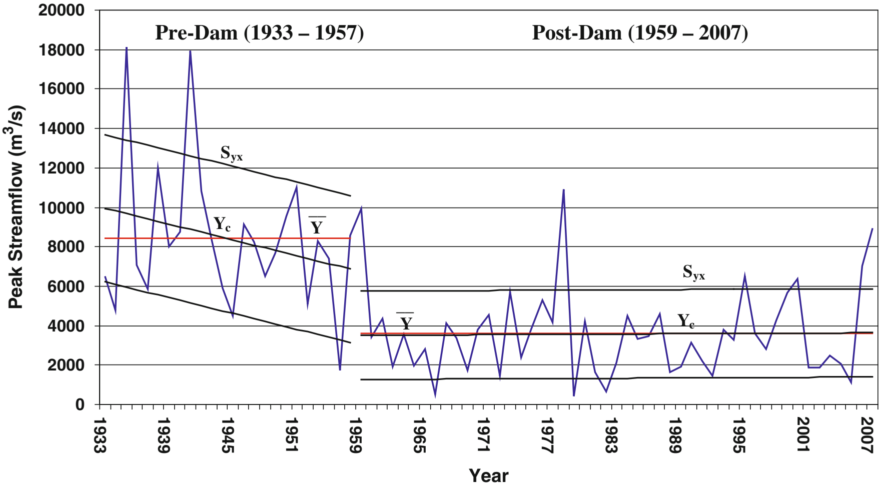

Fig. 4.7 Trend of peak flow of the lower Damodar River in pre-dam and post-dam periods
Yc = 8412.5+{(−133.87)} x, S*yx* = 3, 988 m3/s, Average peak discharge (Y) = 8, 413 m3/s (Pre-dam, 1933–1956)
Yc = 3564.95 + {(−2.69)} x, S*yx* = 2, 241 m3/s, Average peak discharge (Y) = 3, 607 m3/s (Post-dam, 1959–2007)
Data Source: Refer to Appendix F

Figure 4.6 shows a decrease of peak flood in both periods. In the pre-dam period, the peak flow decreases gradually due to extraction of water by industry with a trend line Yc = 8,412.5 + {(−133.87)}x. As expected, the peak discharge varies on either side of the trend line. In the pre-dam period the standard error of estimate is ±3,988 m ^{3}/s.

In the pre-dam period, in any year, the actual peak streamflow may be expected to lie within 3,988 m^3/s on either side of the computed peak discharge. The peak discharges of 18,112 m^3/s (1935) and 17,942 m^3/s (1941) are abnormally high, exceeding the expected range of discharge fluctuations as given by Syx±3,988 m^3/s. The actual departures in these 2 years were +8,427.74 and +9,060.96 m^3/s respectively. These two high peak floods are clearly outliers. Similarly, the peak discharges of 4,793 m^3/s (1934) and 1,714 m^3/s (1955) are abnormally low, exceeding the normal range of discharge fluctuations as given by Syx ± 3,988 m^3/s. The actual departures in these 2 years were –5,025.14 and –5,292.87 m^3/s respectively. In the post-dam period, the trend line follows the equation of $\text{Yc} = 3,607.42 + \{(-56.74)\}\text{x}$, and in that period the standard error of estimate (Syx) is ±2,241 m ^{3}/s. The peak discharges of 8,792 m^3/s (1959), 10,919 m^3/s (1978) and 8,883 m^3/s (2007) are abnormally high and the discharges of 6,522 m^3/s (1995) and 6,387 m^3/s (2000) also exceed the expected range of discharge fluctuation of ±2,241 m^3/s. The peak discharge figures of 503 m^3/s (1966), 413 m^3/s (1979) and 666 m^3/s (1982) are abnormally low and are designated as drought years (Bhattacharyya 1998).

4.2.3 Modification of Hydrographs in the Post-dam Period

Due to regulation of the reservoirs, flood peaks were significantly reduced after dam construction. Under natural conditions, i.e. in the pre-dam period, floods occurred mostly in July or August. In the post-dam period, however, the August floods are kept in check by filling the DVC dams full to the brim. In the hydrological cycle, water infiltrates the ground up to July–August whereas in September, the soil becomes completely saturated and water flows to the river. There is local belief that rainfall in the "Hathia" (the period between September 25th and October 10) is very crucial to the yield of rice. Hence, water is stored behind dams to be released to meet the probable shortage in September and October. If it happens to rain in September, however, water stored behind the dam has to be released in all its fury; the consequence is an inevitable flood (Bhattacharyya 1998). From the hydrographs of the Damodar at Rhondia in pre-dam and post-dam periods, it is found that peak streamflow has been shifted from August in pre-dam to September in the post-dam period (Fig. 4.8). It is worth noting here that the devastating floods of 1978 occurred in the month of September (Fig. 4.9).

4.2.4 Flood Hydrology

Floods are hydrological events, independently distributed in time and characterized by their magnitude and recurrence interval (Sharma 1976). The magnitude of an extreme event is inversely related to its frequency of occurrence i.e., very severe events occur less frequently than more moderate events. The annual maximum discharge is often used in developing a flood frequency distribution.

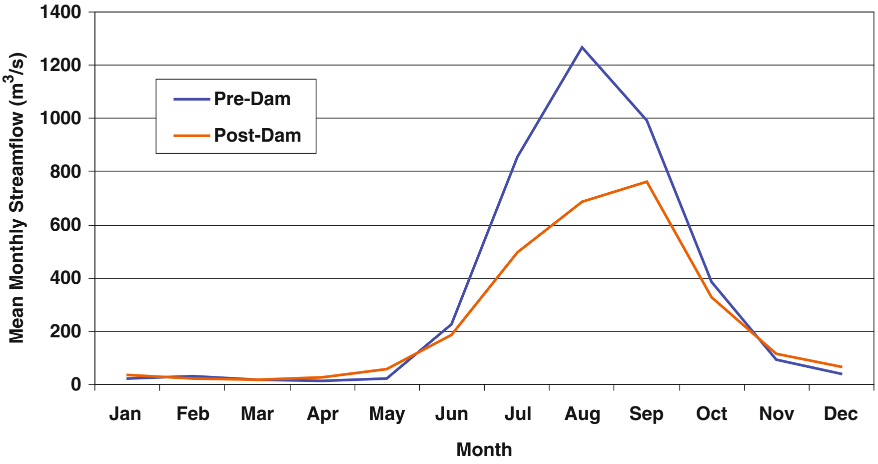

Fig. 4.8 Hydrographs of the lower Damodar River in pre-dam (1934–1956) and post-dam (1959–2007) periods
The representative average monthly streamflow for the pre-dam (1934–1956) and post-dam (1959–2007) is computed by taking the average streamflow during each month, adding these for the period 1934–1956 and 1959–2007, and dividing the total by number of months of data availability.
Data Source: Refer to processed data in Appendix C

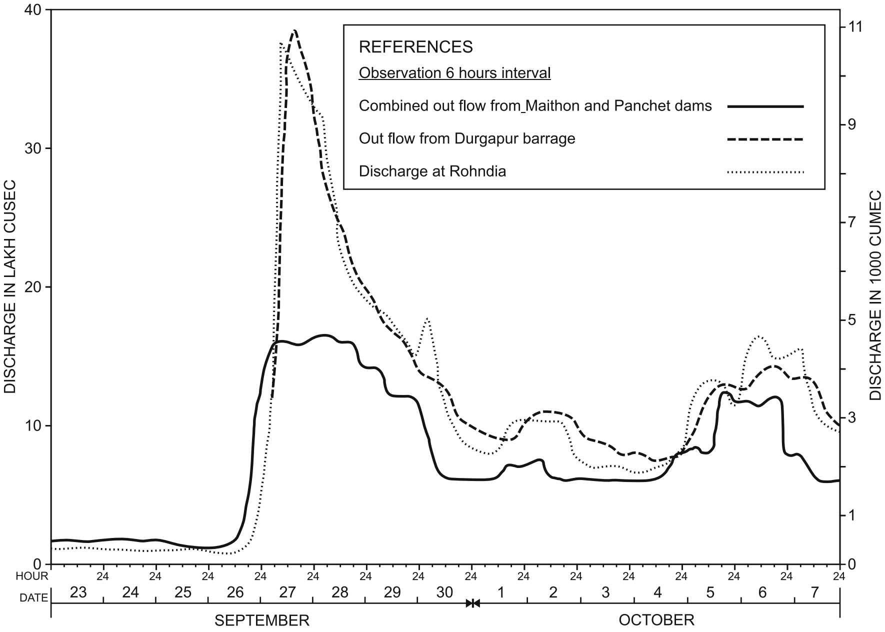

Fig. 4.9 Flood hydrographs of the lower Damodar River at different sites during Sept–Oct 1978 flood (Data source: PK Sen 1993)

There are several methods for flood frequency analysis. These methods consider either full or partial series. A series is constituted by the recorded events of peak flows over a given period of time. In the full series only the highest magnitude of flood during a given year and in the partial series flood occurrences more than once above the assumed magnitude is considered for analysis. The full series may be analyzed for flood frequency by several of the empirical, statistical or graphical methods (Chow et al. 1988; Sharma 1976). Hydrologic systems are sometimes affected by extreme events such as severe storms, floods etc. In this analysis the first asymptotic distribution of extreme values (Gumbel 1941) has been used in order to compute annual flood data.

Under the natural condition the mean annual flood (q2.33) and the most probable annual flood (q1.58) are of the order of 8,417 and 6,728 m^3/s respectively whereas 7,000 m^3/s has a recurrence interval of only 1.67 years. The bankfull stage of 7,080 m^3/s has a recurrence interval of 1.7 years. Thus the Damodar at the hydrometric station was subjected to frequent floods in and around Rhondia and in the entire trans-Damodar catchment i.e., below Paikpara. Discharges of 10,000 and 20,000 m^3/s have recurrence intervals of 3.60 and 96.41 years respectively (Bhattacharyya 1998, 2000b). In the post-dam period (1959–2007), the regulated flow due to dam closure does not actually conform to the theory of extreme values. For want of a proper statistical hypothesis to deal with the distribution of such hydrologic phenomena, the asymptotic theory, as has been applied to extreme yearly floods under natural conditions of the watershed, has been applied for the post-dam period (Sharma 1976).

Under the artificial conditions of the catchment, the mean annual flood and most probable annual flood are of the order of 3,630 and 2,604 m^3/s respectively, flows well below the bankfull stage at Rhondia. The return period for the bankfull stage of 7,080 m^3/s has been increased to 14 years. In probabilistic terms, a 14-year flood means a 1-in-14 chance of occurring in any given year. So it is evident from the above that the probability of occurrence of floods has been reduced during the post-dam period. The return period of floods of 10,000 m^3/s has been increased from 4-year, pre-dam, to 66-year, post-dam, and shows the definite flood moderation capability of the DVC dams (Tables 4.5, 4.6, 4.7).

According to available data (Appendix F), peak floods exceeding 10,000 m^3/s at Rhondia occurred five times before dam closure between 1933 and 1957. After dam closure, combined peak inflow of 10,000 m^3/s in the DVC dams (Maithon and Panchet) occurred fourteen times (Table 4.6; Appendix G; Fig. 4.10). During October 1959, peak inflow into the reservoirs of 17,641 m^3/s was moderated to 8,155 m^3/s. The outflow recorded at Durgapur barrage was 9,911 m^3/s due to the contribution from the intermediate catchment. "It has been recorded by the DVC that had there been no dams, a flood of 22,939 m^3/s would have been experienced below the Durgapur barrage which was much higher than the highest recorded flood of 18,406 m^3/s till that time" said DVC Engineer, Debashis Ghosh (personal communication March 14, 1997). Highest combined inflow at Maithon and Panchet has been recorded as 21,070 m^3/s on September 27, 1978. This was moderated to the combined outflow of 4,616 m^3/s (Tables 4.6, 4.7). It is evident from the Table 4.6

Table 4.5 Flood frequency analysis

			Recurrence interval					
			In years for discharge (m^3/s) value of					
Periods	$\overline{X}$ (m^3/s)	s.d	7,000	7,080	10,000	20,000	$q^{1..58}$ (m^3/s)	$q^{2..33}$ (m^3/s)
Pre-dam (1934–(1956)	8,413	3,730	1.67	1.7	4	96	6,728	8,417
Post-dam (1959–(2007)	3,607	2,265	12.51	14	66	18,811	2,607	3,630

Most probable flood ($q = 1.58$ years, Peak discharge corresponding to a return period of 1.58 years Mean annual flood (q =2.33 years, Peak discharge corresponding to a return period of 2.33 years). Computed by the author based on data in Appendix F

Table 4.6 Performance of Damodar valley reservoirs (Maithon and Panchet) in combined flood moderation during major flood periods

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
Sept, 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

Examination of maximum inflow and maximum outflow data for the two lower dams at Maithon and Panchet show 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 m^3/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 m^3/s occured during 1959, 1978 and 1995 and were successfully checked.
Data Source: DVC (1995), MRO office, DVC Maithon.

that flood moderation to the extent of 32–80% had been achieved in the high flood years. Detailed examination of flow data as available from 1958 to 2007 from the DVC record shows (Appendix G) that the magnitude of the design flood from the Panchet and Maithon has been reduced by an average of 56% due to flood management by DVC dams. Jain et al. (1973) reported that the magnitude of the design flood

Table 4.7 Performance of Damodar valley reservoirs (Maithon and Panchet) in 1978 flood (m^3/s)

	With 4 DVC dams		Without dams	
	3 Hourly peak inflow	3 Hourly peak outflow	3 Hourly peak inflow	3 Hourly peak outflow
At Maithon and Panchet	21,917	4,615	26,958	26,958
At Durgapur	10,732	10,732	33,414	33,414

Without dam intervention, the river would have generated a probable peak of 33,414 m^3/s at Durgapur barrage, thus exceeding the design flood of 28,320 m^3/s.
Computed by the author based on data availability shown in Appendix F

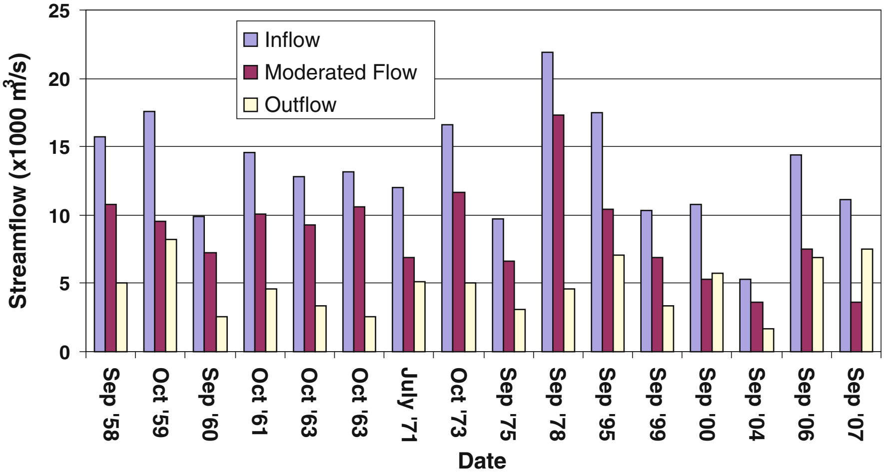

Fig. 4.10 Combined moderation by Maithon and Panchet dams during major floods. Data source: Refer to Appendix G

from the Panchet reservoir would be reduced by 80% subsequent to dam closure. According to a similar report made by Huggins and Griek (1974), the mean annual flood along the Blue river, Colorado has been reduced by nearly 40% since reservoir construction. Indeed, reduction of flood peaks by 20–75% has been widely reported by others (Lauterbach and Leder 1969; Moore 1969; Kinawy et al. 1973).

The return period of floods of different magnitudes worked out for the 24-year period (1933–1956) and 48-year period (1959–2007) shows that for the pre-dam period (1933–1956), 7,800 m^3/s is a 2-year flood, 11,095 m^3/s a 5-year flood, 13,276 m^3/s a 10-year flood, 16,032 m^3/s a 25-year flood, 18,077 m^3/s a 50-year flood, and 20,107 and 22,129 m^3/s are 100-year and 200-year floods respectively. In the post-dam period, 3,255 m^3/s is a 2-year flood, 5,258 m^3/s a 5-year flood, 6,584 m^3/s a 10-year flood, 8,260 m^3/s a 25-year flood, while 9,503, 10,737, and 11,966 m^3/s are 50-year, 100-year and 200-year floods respectively. The Damodar river peak floods during natural conditions (1933–1956) for various return

Table 4.8 Gumble extreme distribution (Type-1)

	Value	
Return Period (year)	Pre-dam	Post-dam
2	78,000.06	3,255.33
5	11,094.78	5,258.23
10	13,276.18	6,584.33
25	16,032.38	8,259.86
50	18,077.08	9,502.86
100	20,106.69	10,736.69
200	22,128.89	11,966.01

Computed by the author based on data availability shown in Appendix B and F

periods are much greater than the post-dam floods for the same return periods (Bhattacharyya 2008). This, however, does not guarantee flood recurrence strictly at those intervals as is evident from the incidence of high flood discharge above 16,992 m^3/s in the 2 years 1935 and 1941 despite the fact that 16,032 m^3/s is a 25-year flood. Similarly, in the post-dam period, high discharges of 6,522 and 6,387 m^3/s occurred in the years 1995 and 2000 although 6,584 m^3/s represents a 10-year flood within the record as a whole (Table 4.8).

When considering the magnitudes of floods of different recurrence intervals before and after dam construction, it is clear that dams have much less effect on rare events of high magnitudes (Petts and Lewin 1979). In spite of flood moderation by the DVC dams, floods occurred in 1959, 1978, 1999, 2000, 2006 and 2007, demonstrating that the lower valley is still vulnerable to sudden floods. TVA Engineer, Mr. Voorduin's project provided for the full control of a "design" flood of 28,321 m^3/s resulting from a rainstorm of 50.8 cm in the upper catchment and for the controlled flood to be limited to the assumed channel capacity of 7,080 m^3/s at Rhondia for which purpose all the dams together required a total flood reserve of 3,595.6 million m^3 (Voorduin 1947). The four dams i.e., the Tilaiya, the Maithon, the Panchet and the Konar provide total flood reserves of 1,292 million m^3. Land acquisition for the Maithon and the Panchet reservoirs up to the top of the gates is yet to be completed. When this is done the flood reserve will be 1,863 million m^3, slightly more than half of what is required for the control of the "design" flood. With this in mind, moderation of a 28,321 m^3/s design flood, or even known floods with a peak of 18,406 m^3/s to the bankfull capacity of 7,080 m^3/s, is not possible at present (DVC 1995; CWC 2001a). DVC engineers are considering alternative storage arrangements, either through acquisition of the remaining inundated land upstream of the existing reservoirs at Maithon and Panchet, or by construction of the Balpahari and the Tail pool dams at Panchet (Chaudhuri 2001, 2006).

Irrigation and power have opposing claims and their demand does always not coincide. As an example, Damodar Valley Corporation (DVC) wants to operate the dam for optimization of power benefits whereas the West Bengal Government wants more water for irrigation downstream. After the devastating flood of 1959,

Table 4.9 Guideline for combined flood release from Maithon and Panchet Dams (June–September)

Percentage of combined flood cushion occupied	Stipulated maximum combined flood release (m^3/s)
Till 20% of the combined flood reserve is occupied	1,982
While using 20–50% of the combined flood reserved	3,398
While using 50–70% of the combined flood reserved	4,531
While using 70–100% of the combined flood reserved	5,663
When 100% of the combined flood reserve is occupied, i.e. Maithon R.L reaches 495 ft (150.88 m), Panchet R.L. reaches 435 ft (132.59 m) and combined inflow is more than 5,663	Balance outflow with inflow

Table 4.10 Guideline for combined flood release from Maithon and Panchet Dams (October)

Percentage of combined flood cushion occupied	Stipulated maximum combined flood release (m^3/s)
Till 20% of the combined flood reserve is occupied	1,982
While using 20–50% of the combined flood reserved	2,265
While using 50–70% of the combined flood reserved	3,398
While using 70–100% of the combined flood reserved	4,531
When 100% of the combined flood reserve is occupied, i.e. Maithon R.L reaches 495 ft (150.88 m), Panchet R.L. reaches 435 ft (132.59 m) and combined inflow is more than 4,531	Balance outflow with inflow

Source: CWC (2001a).

the government of West Bengal requested the DVC to adopt a new water release schedule in 1961, resulting in heavy encroachment on the flood reserves of the DVC reservoirs. According to this new schedule, an outflow of 5,660 m^3/s can be released in the monsoon months (June–September) only when 70–100% of the available flood reserve, 740–1,050 million m^3, has been used up. The outflow is to be limited to 3,400 m^3/s until 50% of the flood reserve, 500 million m^3, is used and is to be increased to 4,500 m^3/s when 50–70% of the flood reserve, 500–750 million m^3, has been used up (Tables 4.9 and 4.10). In October, the outflow is regulated even more strictly (DVC 1966; CWC 2001a; Bhattacharyya 1998, 2002).

4.3 Changing Flood Behavior in the Lower Part of the Lower Damodar River

The flow regimes and channel capacities described in the previous section do not hold well for the whole stretch of the Damodar Valley, and large portions of it remain vulnerable to floods. The bankfull capacity of the Damodar River below the confluence with the Barakar decreases significantly from 7,080 m^3/s at Durgapur.

The Lower Damodar in general and the lower section of the Lower Damodar in particular, i.e. the Amta Channel along with other distributaries and Khal (Kana Nadi) has risen considerably due to siltation and encroachment on the riverbed. The actual carrying capacity of the Damodar is only 4,531 m^3/s below Durgapur and at Amta it is only 849.6 m^3/s even after resuscitation through the Lower Damodar improvement scheme. The outfall is sluiced and, as a result, its deterioration by tidal ingress has been successfully checked. The Mundeswari River can hardly carry 2,832 m^3/s; thus, any flow above 2,832 m^3/s at Durgapur can cause floods downstream (CWC 2001a). The primary consideration in the flood control strategy of the DVC dams is to provide adequate protection to the left bank embankment along the Damodar River as it protects the mining and industrial areas, important towns, as well as railways and roadways. The rural and undeveloped lower reaches of the valley, covering about 780 km^2, however, are totally neglected (Bhattacharyya Asit K 1973). The left bank has now been strengthened to withstand a controlled flow of up to 12,743 m^3/s (CWC 2001a). The inadequate capacity of the Maithon and Panchet reservoirs has necessitated high water releases during high rainfall conditions (Sen 1985a, b). The uncontrolled run-off in the catchment below dams may augment this discharge at Durgapur and Rhondia by more than 2,832 m^3/s. It must be remembered that the uncontrolled catchment area below Maithon and Panchet Dams and up to Durgapur is 2,295 km^2 and between Durgapur and the Rupnarayan river it is 2,460 km^2. This catchment itself can generate a flood intensity of 5,663 m^3/s (CWC 2001a). In the trans-Damodar distributary channels, the subsurface water yield is very high in the event of excessive rainfall. Other contributory factors to flooding include spilling of the Dwarakeswar river, flood in the Rupnarayan river as well as adverse conditions of the Hooghly river including temporary factors such as the occurrence of a high tide coming up from the Bay of Bengal (Bhattacharyya Asit K 1973; Sen 1985a; Bhattacharyya 1998, 2002).

The flood history of the Damodar during the period 1857–1917 is summarized in the EL Glass report submitted to the then Bengal Government. The results are based on observations at Raniganj, a few kilometers upstream of Durgapur (Sen 1962). Corresponding data for the pre-dam and post-dam periods at Rhondia have been given (Table 3.3). From 1857 to 1917 there were 33 floods with a magnitude between 5,664 and 8,496 m^3/s. In the later periods, this number was reduced to 11 (1933–1956) and 5 (1959–2007). Only three high floods have occurred in the post-dam period, one in October 1959, one in September–October 1978, and one in September 2007. Before dam construction, floods of the order of 10,000 m^3/s took place every 4 years and were tolerated. But after dam construction a flood as low as 2,604–3,630 m^3/s can create problems in the lower part of the lower reach of the valley due to decrease in channel capacity. At the same time, dams have provided reasonable flood protection in the upper part of the Lower Damodar valley.

Dam construction has been found to have numerous impacts on downstream channel capacity. Wolman (1967) suggested that whether channel capacity increases or decreases following dam construction depends upon the ratio of the pre-dam and post-dam discharges. In Britain, Gregory and Park (1974) have related the reduction of channel capacity to the reduced frequency of peak discharges. The overall effect of the creation of a reservoir by the construction of a dam is to lead to a reduction in downstream channel capacity (Petts and Lewin 1979; Chin et al. 2002). This is true for the Lower Damodar River as well.

4.4 Relationship Between Discharge and Rainfall in Pre-dam and Post-dam Periods

Several decades of rainfall records for the Maithon and Panchet sub-catchment have been assembled and analyzed to identify any significant changes that might have caused morphological response in the riverbed. Monthly total rainfall for the Maithon and Panchet sub-catchment has been recorded from a large number of gauges distributed throughout the Damodar river basin. Hence the mean monsoon rainfall (June–October) has been calculated simply as the arithmetic average of the gauge values. Yearly monsoon maximum and minimum rainfall has been recorded here. Maximum monsoon rainfall for the Panchet sub-catchment within the analyzed period (1892–2007) is about 1,677 mm (1984) and the minimum is about 444 mm (1972). Calculated average long-term (114 years) monsoon rainfall for the Panchet sub-catchment is about 1,134 mm. For the Maithon sub-catchment, maximum monsoon rainfall is 1,994 mm (1998) and the minimum is 467 mm (1924). Calculated average long-term (117 years) monsoon rainfall for the Maithon sub-catchment is about 1,116 mm.

Monsoon total rainfall for the Panchet and Maithon sub-catchments have been evaluated for the period from 1891 to 2007. Although there are considerable year-to-year variations in rainfall, the data does not show any significant trend that could cause systematic change in the catchment flow regimes. The spatial distribution of rainfall over the Damodar river basin, however, directly controls the spatial distribution of runoff with the highest proportion of total annual streamflow confined to the monsoon period (Figs. 4.11, 4.12).

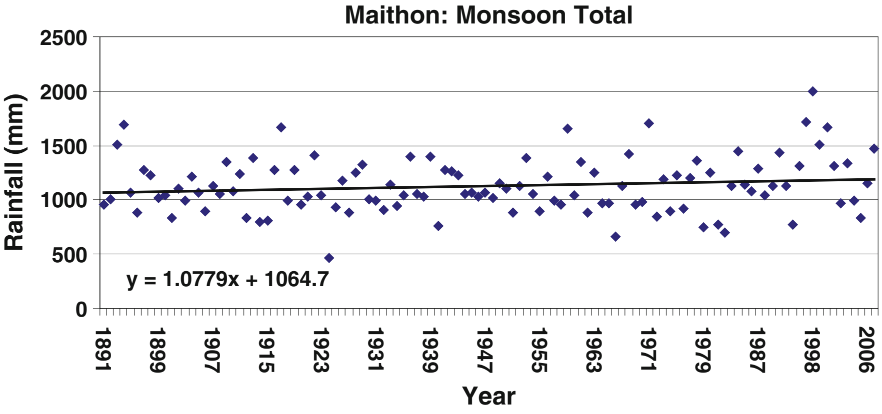

Fig. 4.11 Trend of monsoon rainfall in Damodar basin (Maithon sub-catchment)

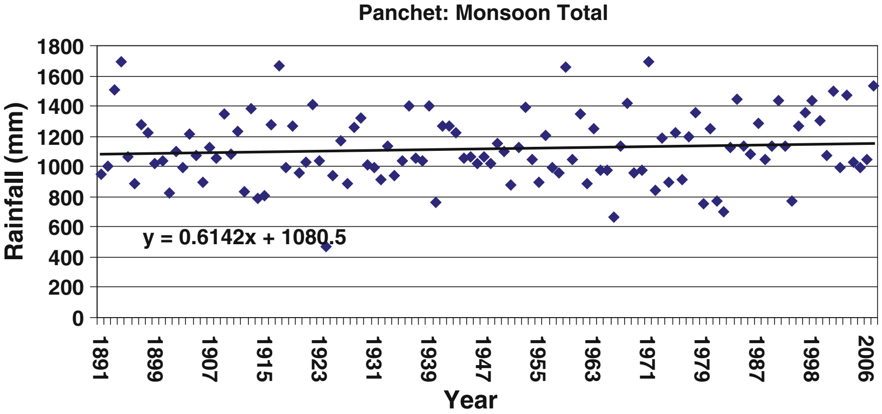

Fig. 4.12 Trend of monsoon rainfall in Damodar basin (Panchet sub-catchment)
Data Source: More than a century of rainfall data from a large number of gauges distributed within the Upper Damodar Valley, which includes the Maithon and Panchet sub-catchments, are available from MRO office of DVC, Maithon. Rainfall data for the monsoon seasons between 1891 and 2007 for both sub-catchments has been assembled and analyzed. The mean monsoon rainfall has been calculated simply as the arithmetic average of the gauge values.

Monsoon discharge was higher in the pre-dam period. Pramanick and Rao (1953) have examined rainfall data for the upper Damodar valley down to Asansol for a period of 60 years, from 1891 to 1950. According to them, high discharge at Rhondia exceeding 5,664 m^3/s on any given date was strongly correlated with the rainfall recorded on that date as well as in the preceding 2 days (Pramanick and Rao 1953; Sen 1962). Rainstorms recorded in the Damodar valley during this period produced high discharge as well as high peak streamflow from the Rhondia weir (Table 4.11). As expected, there is a strong, positive correlation between average annual discharge and rainfall (monsoon) in the Maithon and Panchet sub-catchment during both the pre-dam and post-dam periods. Thus, even in the post-dam period, high rainfall has played a significant role in enhancing discharge below control points (Bhattacharyya 1998). Although discharge at Rhondia and Durgapur is correlated with monsoon rainfall in the Maithon and Panchet sub-catchment, monsoon discharge from the dams has decreased (Table 4.3). This is because surplus monsoon rainfall is stored in reservoirs and then released to satisfy agricultural demand during the non-monsoon period. However, reservoirs are often forced to release enormous amount of water if rainfall exceeds the expected normal during a monsoon event, resulting in the inundation of large areas downstream. In fact, the breaching of embankments is an annual phenomenon in Lower Bengal. Embankments were breached in the Ajay and Damodar rivers during the 1978 floods and so-called safe areas were inundated.

Table 4.11 Relationship between rainstorms recorded at Damodar valley and high discharge at Rhondia on the Damodar

Month	Date								Total storm rainfall in mm	Date and month of occurrence, peak discharge	Magnitude of peak discharge (m^3/s)
1913 (August) Average rainfall in mm	5	6	7	8	9	10	11				
	8	36	82	108	51	24	5		314	Aug 8	18,406
1935 (August)	10	11	12	13	14	15					
	22	59	115	53	24	13			288	Aug 12	18,112
1958 (September)	14	15	16								
	18	71	79						166	Sep 16	4,682
1959 (September–October)	30	1	2	3	4	5	6	7			
	10	52	90	8	5	33	18	15	231	Oct 2	8,792
1978 (September)	26	27	28	29							
	63	97	20	4					184	Sep 27	10,919
2007 (September)	–								–	Sep 25	8,883

After Bose and Sinha (1964).

4.5 Changes in Suspended Sediment Concentration

Apart from changing a river's flood regime, dams also function as effective sediment traps. The reduction in sediment supply, combined with the change in flow regime, can affect the downstream channel substantially. Several examples can be cited that indicate a significant downstream decrease in sediment load. Williams and Wolman (1984) showed that such effects extended up to hundreds of kilometers downstream from the 21 large American structures that they examined. For the Glen Canyon Dam on the Colorado River (US Bureau of Reclamation 1976), the average annual pre-dam and post-dam suspended sediment loads as measured 150 km downstream at the Grand Canyon are as follows: pre-dam (1926–1962), 126 million megagrams; post-dam (1963–1972), 17 million megagrams with a reduction of about 87%. Similarly, on the Missouri River at Bismarck, North Dakota, 121 km downstream from the Garrison Dam, sediment loads during 1949–1952 averaged 48.6 million megagrams per year. After dam closure in 1953, the sediment load measured during 1955 was 9.8 million megagrams and during 1959 it was as reported only 5.3 million megagrams (Williams and Wolman 1984).

Data for the Damodar River also shows a significant decrease in suspended sediment concentration after dam construction. For the Lower Damodar, the average annual pre-dam and post-dam suspended sediment concentration as measured approximately 29 km downstream of Panchet at the Damodar Bridge site are as follows: pre-dam, 1.87 gr/l; post-dam, 0.54 gr/l. There is a reduction of about 72%. The average annual discharge for that period is as follows: pre-dam, 1,993.42 m^3/s, and post-dam, 2,693.72 m^3/s, showing a 35% increase in average annual discharge from the Damodar Bridge site.

Figure 4.13 shows the relationship between discharge and suspended sediment concentration of the Damodar River at the Damodar Bridge site in 1953 and 1954. Because of a lack of vegetation at the end of the dry season, the early monsoon rains result in the highest sediment load. High temperature and moisture weather the rocks and these eroded loose materials are carried along with the first half of the monsoon discharge. A study of the daily suspended sediment concentration and discharge in 1953 reveals several occasions when the peak suspended sediment concentration has taken place either one or a few days earlier than the maximum discharge. The behavior of suspended sediment concentration is different in the post-dam period due to trapping of the sediment in the reservoirs. There are several instances where such lag between the maximum values of discharge and sediment concentration is not obtained in the post-dam period (Fig. 4.13).

In the pre-dam period, average suspended sediment concentration (June–October) was higher than that of the post-dam period. In both cases the highest sediment concentration is found in the month of July. To understand precisely the relation between the suspended concentration (L) and discharge (Q), the correlation co-efficient is calculated and here the value of "r" indicates that the correlation is positive but not high. A relatively low correlation is observed post-dam because the dams act as sediment traps for the sediment received from the upper catchment (Fig. 4.14).

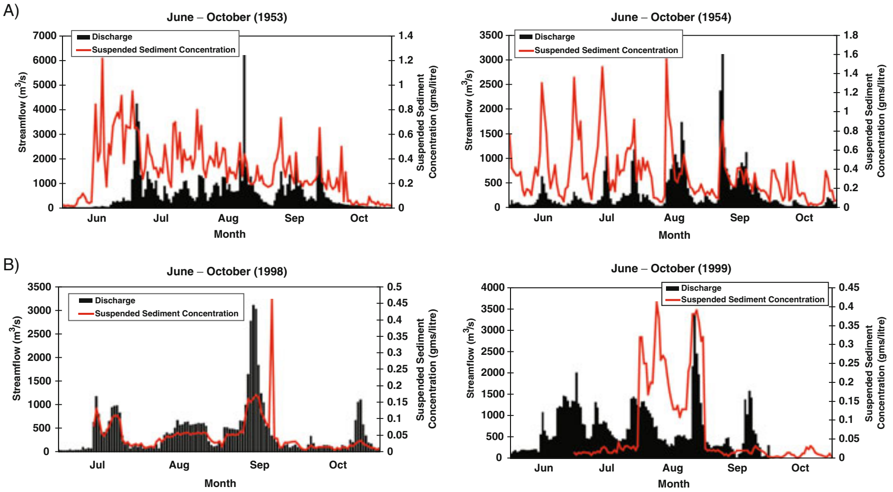

Fig. 4.13 Monsoon discharge and suspended sediment concentration at Damodar bridge sites (June to October, 1953, 1954, 1998, 1999)
The specific instances, as observed from the data, are the occurrence of highest suspended sediment concentration on 28th June of 0.9130 g/l, followed by a maximum discharge of 406.65 m^3/s on 29th June. Similarly, in July, maximum sediment concentration 0.9530 g/l on 3rd July is followed by a maximum discharge of 4,239.76 m^3/s on 5th July. Maximum sediment concentration of 0.5290 g/l on 22nd August is synchronized with the maximum discharge of 6,194.86 m^3/s on 24th August. In September, the maximum sediment concentration of 0.7350 g/l on the 10th corresponds to maximum discharge of 2,087.55 m^3/s on the 17th. In 1954 the specific instances, as observed from the data, are the occurrence of highest sediment concentration on 16th June of 1.3020 g/l followed by maximum discharge of 636.01 m^3/s on 17th June. Similarly, in July, maximum sediment concentration of 1.4687 g/l on 14th July is followed by maximum discharge of 1,048 m^3/s on 16th July. Maximum suspended sediment concentration of 1.5515 g/l on 13th August is synchronized with the maximum discharge of 516.27 m^3/s on the same date. In September, the maximum suspended sediment concentration of 0.9053 g/l on the 8th corresponds to maximum discharge of 3,107.19 m^3/s on the same day.

In 1998 the occurrence of highest sediment concentration of 0.46 g/l on 6th September corresponds with the maximum discharge of 3,113, 3,029 and 1,836 m^3/s on the 30th and 31st of August, and the 1st September respectively. Similarly, in 1999 maximum sediment concentration of 0.41 g/l on the 9th of August is associated with the maximum discharge of 1,128.75 and 1,054 m^3/s of the previous few days.
Data source: Appendix B

Data for several other dams also indicate a significant decrease in sediment load after dam construction. A clear demonstration of this effect has been given for the South Saskatchewan River in Canada by Rasid in 1979 (Goudie 1990). There has been a reduction of about 87% in sediment load after construction of the Glen Canyon Dam on the Colorado River since sediments are now trapped upstream of the dam in Lake Powell. Sediment retention is also illustrated by the case of the Nile where downstream annual sediment loads 2 years after dam closure were observed to be only 20% of pre-dam values (Hammad 1972). Until the construction

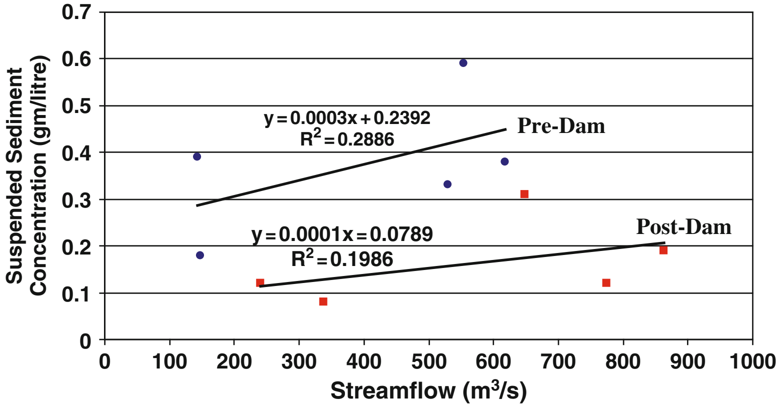

Fig. 4.14 Linear regression of average monsoon discharge and suspended sediment concentration at Damodar bridge site on the Damodar River in pre-dam and post-dam periods. Data source: Hydraulic Data Division, DVC Maithon

of the Aswan dam, late summer and autumn discharge was characterized by high silt concentration. Now the silt load is lower throughout the year and seasonal peaks have also been removed (Goudie 1990). Petts (1984) states that the Nile only transports 8% of its natural load below the Aswan High Dam. Other rivers for which data are available carry between eight and 50% of their natural suspended loads below dams (Petts 1984; Goudie 1990).

It must be noted that the data may not accurately reflect actual trap efficiency since measuring stations are at considerable distances downstream from the dams. The entrance of major tributaries, sediment supplies from the bed and banks immediately downstream from the dam, and various other factors can affect the apparent trend (Dolan et al. 1974; William and Wolman 1984). Budhu et al. (1994) recorded that sediment concentration near Lees Ferry was in excess of 10,000 parts per million (ppm) prior to dam construction but is now about 200 ppm. Prior to the construction of the Glen Canyon Dam, receding floodwaters deposited large amounts of sediment that replenished scoured bars and built new ones. In the post-dam period, only the suspended sediment load below the dam is available for bar replenishment.

The Damodar gets an enormous quantity of eroded materials from the uncontrolled catchment below the dams. There is a substantial growth of coal mining in the Ranigunj Coalfield. The coal mining-based industries, coal washeries, refractories, and significantly developed iron and steel industries in Burnpur and Durgapur have changed the whole landscape of the Lower Damodar basin into one filled with industrial smoke and coal spoils. The Durgapur-Asansol industrial belt has no perennial source of water and is served by the feeder canal of the Damodar Valley Corporation. Besides feeding the industrial complex, the canal releases water in lean months for agricultural use in neighboring districts. The only source for drawing water is the Damodar River which receives industrial pollutants through two storm water drains, the Nunia Nala in the Asansol region and the Tamla Nala in the Durgapur region.

It also receives polluted water through some drains from the Iron and Steel Co. (Burnpur), the Bengal Paper Mill (Raniganj), and the Durgapur Steel Plant (Waria). Thus the sediments and water in and around the Durgapur-Asansol region are filled with toxic chemicals. The thermal power plants contribute about 21.08,203 m^3/day (79.13% of total) of waste water discharges, the largest portion (about 92%) coming from the Durgapur power station. Fly ash constitutes the main pollutant. It has a substantial metallic toxic load, negligible non-metallic toxic load, and BOD (CPCB 1992). The river Damodar receives mine water discharge in the range of 0.2–0.5 million m^3/day. An analysis of water from several mines has indicated that majority of the mine water of this region is not acidic. It is free from toxicity and salinity (Kumar et al. 1993).

In the Damodar river 13,276 m^3/s, a 10-year flood for the pre-dam period has been reduced to 6,584 m^3/s a reduction of about a half, a 5-year flood had been reduced from 11,095 to 5,258 m^3/s and a 2-year flood from 7,800 to 3,255 m^3/s with a reduction of 53 and 58% respectively (Table 4.8). The main channel flows are no longer capable of removing sediments created by flash floods. The sediments are mostly non-compact sand and the quantity of sediment introduced from non-regulated sources exceeds the regulated capacity resulting in aggradation. The trapping of sediment and the lack of flushing due to reduction in peak discharges have inevitably transformed the Lower Damodar into an ecologically imbalanced area (Sen 1985a; Bhattacharyya 1995, 1998). The controlled release downstream from the Maithon and Panchet dams has been further depleted through irrigation intakes from the Durgapur barrage and the Rhondia Weir. In a reach beginning about 74 km downstream from the dams, this decrease in flow volume, combined with deposits from unregulated embankment-free areas and tributaries, has resulted in a river that is full of sand bars and, in many places, at an elevation higher than the adjoining

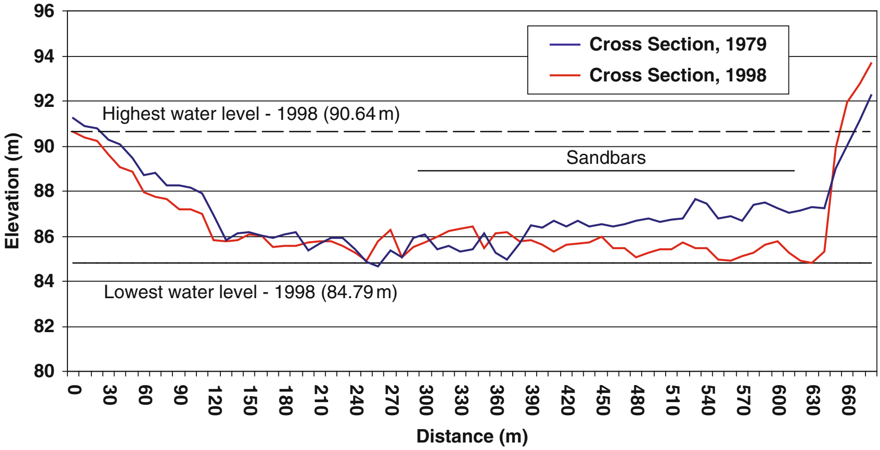

Fig. 4.15 Cross sections of the Damodar River at 36 m downstream from Damodar bridge site (surveyed on 5-9-79 & 4-23-98). Data Source: Hydraulic Data Division, DVC Maithon

land. Lawson (1925) reported similar effects downstream from the Elephant Butte Dam on the Rio Grande River. Within a decade of the closure of the structure, the channel had become choked with sediment from tributaries and the main channel was unable to transport due to reduced flow (Lawson 1925; Fiock 1931).

The contemporary riverbed of the Lower Damodar is choked with sediments below major control points. The river is full of stabilized sandbars and many transient bars are in a process of stabilization. A large portion of the sediments have been contributed by major floods in the pre-dam period, and through overland flows from embankment-free mining industrial urban areas. Even today, the Damodar continues to carry a huge sediment load during floods (Fig. 4.15).

4.6 Silting of the Reservoirs

Accumulation of sediment behind a dam is a universal phenomenon. More than half of the sediments from controlled river basins are trapped by dams and about 25–30% of sediments worldwide are intercepted by large dams if uncontrolled basins are included (Vörösmarty et al. 2003). Dendy et al. (1973) and Dendy and Bolton (1976) summarized the reservoir sedimentation data base of the United States through 1973. By relating reservoir properties to sedimentation rate, these papers have provided a guide for estimating reservoir sedimentation worldwide. Renwick (1996) summarized the database through 1975 and focused on sediment yields as related to the properties of the contributing watersheds (Stallard et al. 2001; Mixon 2002). The Stallard et al. (2001) report is based on the updated Reservoir Sedimentation Information System (RESIS) database referred to as RESIS–II. Research studies on reservoir sedimentation concluded that the deposition of stream-borne sediment causes a reduction of the storage capacity of reservoirs (Dendy et al. 1973; Dendy and Bolton 1976; Renwick 1996; Kondolf and Matthews 1993; Kondolf 1997; Stallard et al. 2001; CWC 2001b; Mixon 2002; Chaudhuri 2001, 2006; Bhattacharyya 2003).

In the Damodar upper catchment, land management and vegetal cover are poor and the rate of sediment production is far in excess of the rate assumed at the time of planning. The upper Damodar catchment is fan-shaped and conducive to a heavy concentration of floods, while the catchment downstream is a very narrow strip. The total catchment is broadly classified as 20% forest area, 50% cultivated land, 25% wasteland and 5% villages, rivers, tanks, and towns. The average annual rainfall is 1,270 mm with a range of about 760–2,030 mm (DVC 1997). The Damodar River has a drainage basin of 18,676 km^2 above Raniganj where the maximum discharge was 18,408 m^3/s in the pre-dam period (Stevenson et al. 1919). The river carried sand loads during high floods and began carrying an enormous sand load, particularly after 1830 when several collieries in the Raniganj coalfield were flourishing. Coal was known to exist in the area as early as 1774 and was worked in 1777 (Hunter 1877). Due to extensive deforestation and unscientific mining, the Damodar transported an enormous sand load during floods and formed char land or sand bars (Bhattacharyya 1998, 1999). In later periods, denuded forest and vegetal cover, poor land management, and badly eroded land prevalent in catchment areas of Maithon, Panchet (CBIP 1981), Konar (CWC 1999) and Tilaiya were responsible for high sediment yield in these reservoirs (Bhattacharyya 2003).

The sedimentation rate in Tilaiya is about 2,857 m^3/km^2/year (CWC 2001b; Bhattacharyya 2003). In the Panchet Hill reservoir, 55.5% of the dead storage space is filled with sediment. At the same time, 36.1% of the live storage space and 2.6% of the flood storage has also been lost in the 39 years up to 1995. In the Maithon reservoir, 55% dead storage space and 27.3% live storage space had been lost as of 2001. The sedimentation rate at the Panchet reservoir has fallen after the construction of the upstream reservoir at Tenughat. However, silting of the Panchet and Maithon reservoirs still has significant consequences below the reservoirs (Tables 4.12, 4.13, 4.14).

Table 4.12 Sedimentation data of Maithon reservoir (based on 2001 survey)

Storage	Initial capacity (1,000 hm)	Present capacity (1,000 hm)	Loss of capacity (1,000 hm)	Loss of capacity (%)
Dead storage up to EL 119 m	20.66	9.33	11.33	55
Live storage EL 119–125 m	60.72	44.15	16.57	27.3
Flood storage EL 125–136 m	38.23	33.38	4.85	12.6
Over all up to EL 136 m	119.61	86.85	32.76	27.4

Source: After DVC, Maithon.

Table 4.13 Rate of sedimentation in Maithon reservoir (m^3/km^2/year)

Interval in years	Number of years	Rate of sedimentation
1955–1963	8	1,524
1955–1965	10	1,429
1955–1971	16	1,333
1955–1979	24	1,238
1955–1987	32	1,290
1955–1994	39	1,280
1955–2001	46	1,132

Computed by the author.

Table 4.14 Sedimentation data of Panchet reservoir (based on 1995 survey)

Storage	Initial capacity (1,000 hm)	Present capacity (1,000 hm)	Loss of capacity (1,000 hm)	Loss of capacity (%)
Dead Storage up to EL 119 m	23.63	10.50	13.13	55.5
Live storage EL 119–125 m	25.24	16.12	9.12	36.1
Flood storage EL 125–136 m	109.30	106.38	2.91	2.6
Over all up to EL 136 m	158.16	132.99	25.17	15.9

Source: After DVC (1995), Bhattacharyya K (1999–2000, 2003).

4.6.1 *The Construction of an Upstream Dam*

The construction of upstream reservoirs is an extremely effective sediment control measure, especially when the sediments trapped in tanks are recovered by farmers during pre-monsoon for use as a soil additive (Morris 1995). A good example of the effect of upstream dams is cited below.

The Panchet Hill dam across the river Damodar, combined with the two upstream dams Konar and Tenughat, intersects the yield from a total catchment of 10,039 km^2. In the upper Damodar watershed, the unterraced wastelands and uplands are subject to serious sheet erosion. A great deal of destruction to the gully area is also present wherever the ground approaches a main riverbed. Vast stretches of undulating forested terrain is subject to serious sheet and gully erosion as well (DVC 1997).

Table 4.15 Decrease in rate of sedimentation in Panchet reservoir due to upstream reservoir (m^3/km^2/year)

1962	1964	1966	1974	1985	1996
1,330[1]	1,240[1]	1,050[1]	1,000[1]	670[2]	648[2]

[1] For Panchet Hill catchment including Tenughat catchment.
[2] For Panchet Hill catchment excluding Tenughat catchment.

With the construction of an upstream dam at Tenughat in 1970, sediment inflow into the Panchet Hill reservoir has been reduced (Table 4.15). It has been estimated that, up to the time of the fourth capacity survey (1974), the Tenughat reservoir intercepted about 31 million m^3 of sediment which would otherwise have moved towards the Panchet Hill reservoir. The average annual rate of deposition during the first 10-year period (1956–1966) after the construction of the Panchet Hill Dam was 10.6 million m^3. After the construction of Tenughat Dam, the average annual rate of deposition has fallen by 60% to 3.5 million m^3 in the 22-year period from 1974 to 1996. According to the sixth survey, the total available capacity of the Panchet Hill Reservoir in January 1996 was 1,358.09 million m^3 up to a reservoir level of 135.6 m above mean sea level. As the original capacity of the reservoir up to this level was 1,581 million m^3, the total volume of deposit during the past 40 years since first impounding was 222.91 million m^3. The average annual sediment deposition rate for the 22-year period from 1974 to 1996 was 648 m^3/km^2/year of catchment area (DVC 1997). It is reported that a siltation trap needs to be constructed immediately upstream of Maithon by constructing Balpahari Dam (Fig. 3.5) at about 50 km upstream of the Maithon Reservoir with catchments of 4,400 km^2, for an additional life of 58 years (Chaudhuri 2006).

4.7 Changing Channel Morphology

Because of reduced sediment load downstream from a dam, the channel pattern of a river may be changed from braided to split or single thread, and may tend to become more sinuous (Galay 1983; Williams and Wolman 1984; Andrews 1986; Everitt 1993; Kondolf and Swanson 1993; Hadley and Emmett 1998; Surian 1999). By reducing the magnitude of frequent, moderate floods, dams may lead to channel narrowing through lateral accretion (Church 1995) as riparian vegetation invades the active channel that was formerly scoured of vegetation by frequent floods (Kondolf 1997; Batalla et al. 2004). As the input conditions have been modified through setting up of control structures, the output pattern along with sediment load has changed. Streamflow below the control points has been reduced resulting in changes in channel morphology. In the Damodar River the changes in channel morphology resulted from discharge diminution and diversions for irrigation through canals. Its variation is demonstrated by the condition of meandering and braiding in a shallow alluvial channel with fluctuating regime, characterized by leptokurtic hydrograph. The cause of modification of channel pattern is the imbalance between the process of sediment transfer and energy dissipation. It represents uniquely the unstable condition of a typical tropical seasonal river flowing mostly on a low gradient sector. When a reservoir is constructed a huge quantity of sediment gets eroded and fills the low and medium flow rivers which are already saturated with sediment. The surplus material, which exceeds the carrying capacity of the flow, will deposit in the main channel, particularly in the upper part of the reach. The high flows, after unloading their burden in the reservoir, become clear and cause the downstream bed to degrade. As their ability to transport sediment is greatly reduced by changing flood regime, the amount of erosion is less than the additional accretion resulting from the non-flood season. Quite often the high flow merely shifts the previous deposits from the upper part of the reach to the lower part. In the post-dam period flood peaks have been reduced decreasing the chances of floodplains overflow. All these processes are instrumental behind the unfavorable circumstances prevailing around the downstream channel specially because of the elevated bed and the diminutive level difference between the bed and floodplain (Chien 1985).

4.7.1 Increases in the Sinuosity Index

The term “channel pattern” generally denotes the course of flow of a channel expressed in quantitative terms by the sinuosity index which is defined as the ratio of the observed length (OL) to the expected length (EL). For the sake of convenience, the Lower Damodar from the Panchet Reservoir to its confluence point at the Hooghly River has been divided into five sectors of unequal length for calculation of meandering index for different periods following Muller’s model (1968). The tortuosity of the course of a meandering stream is the outcome of both topographic and hydraulic factors. It is evident that the new channel (surveyed in 1969–1975) is more sinuous than the old one (surveyed in 1929–1930; Table 4.16).

Overall, the majority of the Damodar river system of drainage is characterized by a relatively less sinuous course. While a channel with a sinuosity index of 1.5 or more is considered meandering, the main Damodar channel is considered

Table 4.16 Sinuosity index (Mueller's model) complied from SOI maps surveyed in 1929–1930 and 1969–1975

Damodar river	Average length of bank (km)	Channel length (km)	Air length (km)	C.I	V.I	H.S.I	T.S.I	S.S.I
Bend I								
(1929–1930)	36	37	33	1.13	1.09	30.77	69.23	1.04
(1974–1975)	36	39	33	1.19	1.09	52.63	47.37	1.09
Below Damodar Barakar confluence to wooden bridge near Asansol								
Bend II								
(1929–1930)	25	28	23	1.24	1.11	54.17	45.83	1.12
(1970–1972)	23.5	27	23	1.20	1.04	80	20	1.15
Asansol to Durgapur								
Bend III								
(1929–1930)	21.16	23	21	1.18	1.05	58.33	41.67	1.07
(197–1971)	22.00	28	21	1.33	1.06	81.82	18.18	1.25
Durgapur to Rhondia Weir								
Bend IV								
(1929–1930)	34	37	29	1.26	1.16	38.46	61.54	1.09
(1969–1971)	32	40	29	1.5	1.10	71.43	28.57	1.23
Rhondia Weir to Jujuti Sluice								
Bend V								
(1929–1930)	53	56	37	1.54	1.44	18.52	81.48	1.07
(1969–1970)	52	56	37	1.53	1.43	18.87	81.83	1.07
Jujuti Sluice to Paikpara								

C.I = Channel Index; H.S.I = Hydraulic Sinuosity Index; V.I = Valley Index; T.S.I = Topographic Sinuosity Index; S.S.I = Standard Sinuosity Index.
After Bhattacharyya (1998).

marginally meandering (sinuosity index 1.30) for the whole length below the dams and remarkably straight in the upper reaches up to Barddhaman (sinuosity index 1.04). There has been a significant decrease in topographic sinuosity in the post-dam period. The standard sinuosity index shows a marked increase from the pre-dam to the post-dam period (Bhattacharyya 1998). The slope and grain size of the sediment load act as major determinants of the channel pattern. The areas of greater slope and larger grain size are generally associated with less sinuous courses whereas those of much gentler slope and finer grain size show greater sinuosity (Sen 1993).

From the SOI map surveyed in 1985–1986, a 1994 Satellite image (IRS-IBLISS-2/FCC classified image) and from 2003 LISS-3 scenes of an IRS-ID satellite, it is evident that braiding and anastomosis have also become important characteristics of this river because of the increased number and enlargement of bars between control structures. The Bara Mana is a citable example of an enlarged alluvial bar in the Lower Damodar.

4.7.2 Planform Configuration

Morphological changes along the Damodar River due to controlling include both aggradation and narrowing of channel through lateral accretion. The planform evolution of the Damodar River is illustrated (Fig. 4.16). The configuration of the river in different years has been shown in sequence. The map shows changes in the river between 1854 and 2003. Over the last several decades, the Damodar channel has undergone a general narrowing due to decreases in the flow and increased sediment supply. The channel bed has been aggraded at an alarming rate in some places, whereas the volume of sediment and rate of sedimentation has grown in other areas. Although a lot of the sediment is trapped in the reservoirs, the river still receives a million tons of sediment from the uncontrolled sectors. The capacity of the river to transport this sediment has been reduced due to the reduction of flood peaks making the channel bed a sediment sink with a series of sand bars. This effect is further enhanced due to the coarsening of bed material. In some sections the Damodar channel has been reduced due to excessive sediment deposition just after the great flood of 1978. Channel reduction appears to have been achieved by the accumulation of sediment as shoals that are now vegetated and stabilized with agricultural fields and human settlements.

There are examples of other rivers where a reduction in channel width has been observed over the years. Williams's (1978) pioneering investigations in the case of the river Platte in Nebraska were recently expanded by Murphy and Randle (2004) and Murphy et al. (2005). Williams (1978) has given a dramatic example in the case of the River Platte in Nebraska. He reported that during the nineteenth century, the river channel, which was several kilometers wide at one period, has been reduced to only 10–20% of its previous width. The Rio Grande River below the Elephant Butte Dam in New Mexico, USA was not a braided river prior to the operation of the dam. Since the Elephant Butte Dam began operations, this channel has narrowed by as much as 90% (Everitt 1993). On the Trinity River, California, construction of the Trinity Dam in 1960 reduced the 2-year flow from 450 to 9 m^3/s. Due to dramatic change in the flood regime, the encroachment of vegetation and deposition of sediment has narrowed the channel by 20–60% of its pre-dam width (Wilcock et al. 1996). Graf (2006), observed shrinkage of the entire assemblage of functional surfaces associated with the channel while studying the geomorphic effects of the hydrological change of the Great Plains and Ozark-Ouachita rivers. In the case of the Damodar river, the average width of a particular section, observed at the beginning of the twentieth century (1930), had decreased to 70% of the average width in 1854 (Fig. 4.16). The last 70 years have seen even more rapid narrowing resulting in width that is only 60% (approximately) of the initial value in 1854.

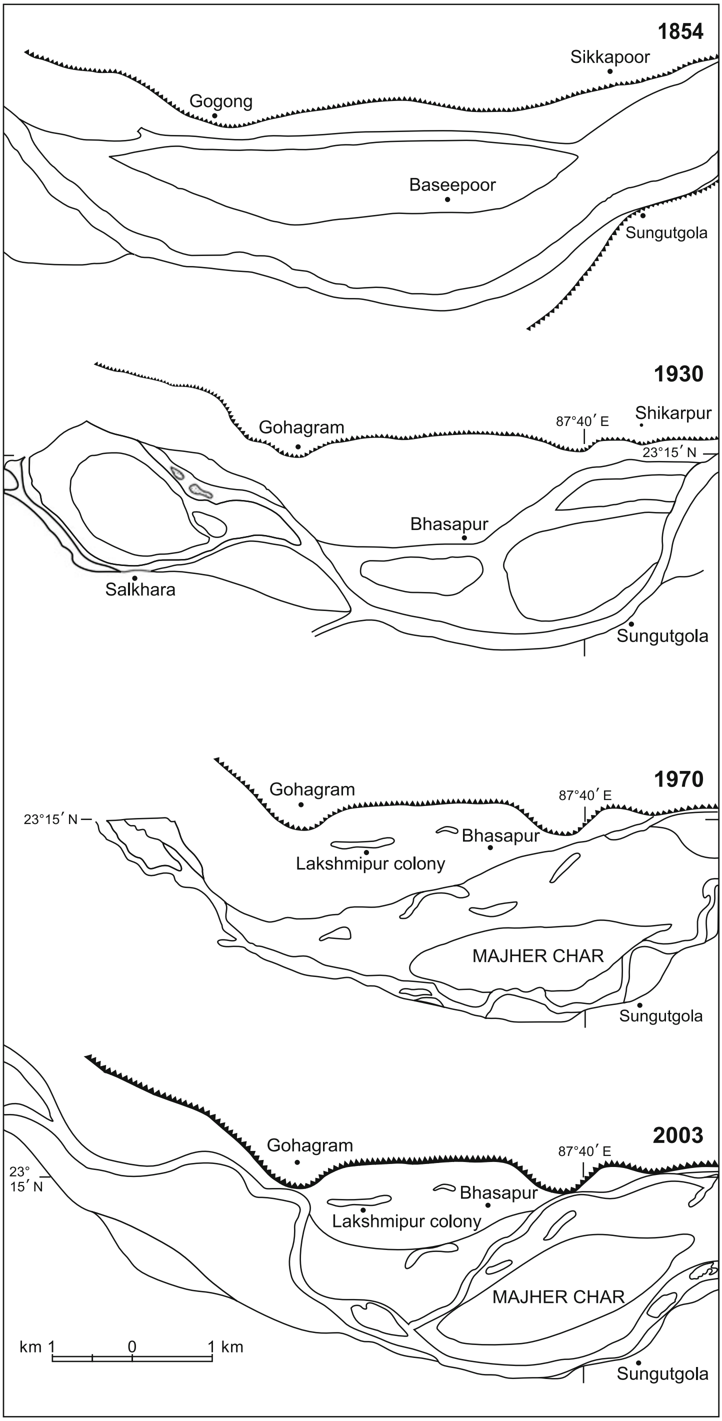

Fig. 4.16 (continued)

4.7.3 Changes in Riverbed Slope

Before the construction of dams, the long profile of the entire Damodar River could have attained a profile of equilibrium because of its pronounced erosional and depositional history since the pre-Cambrian time as is observed from the profile based on Lieut Garnault's slope data of 1864 (Saha 1944). The profile of the Lower Damodar in the post-dam situation from the Damodar Bridge site to its confluence with the River Hooghly (Fig. 4.17) shows remarkably low gradient and slight concavity with a rather inconspicuous break of profile at the bifurcation point where the main Damodar, known as the Amta channel, is bifurcated by its distributary Mundeswari. Its development can be justified by the diversion of maximum discharge into the Kanki-Mundeswari. The inconspicuous break is suggestive of the cessation of the process of sedimentation since the diversion of supply to the Mundeswari. The profile is characterized by sandbars, point bars and formation of gutter channels on a relatively wide river course, indicating the features of a misfit. The computed curve which has been drawn from the bed level elevation of 87.92 m has the lowest decremented value of slope as is evident from log a or b values. The fitness of the observed profile with the computed one drawn from Rhondia up to the outfall of Falta shows that the Yc values considerably increases in the upstream section, whereas they

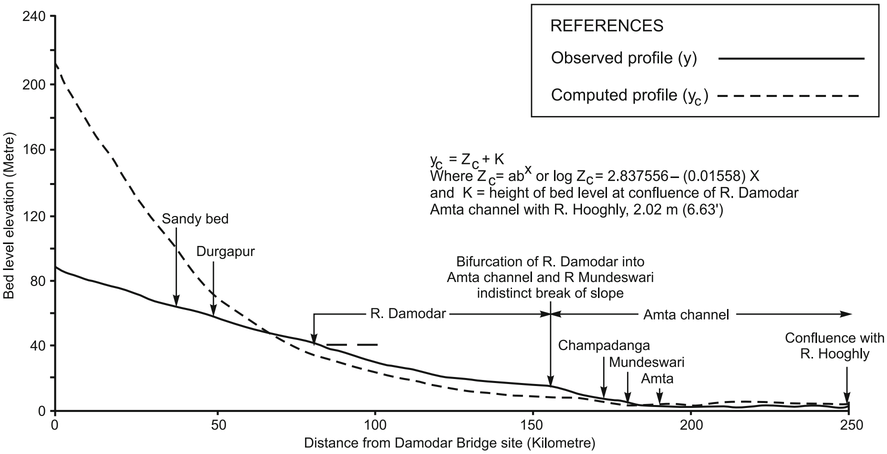

Fig. 4.17 The long profile of the Damodar river (Source: P.K. Sen)

Fig. 4.16 Planform pattern and channel changes for the Damodar River (1954–2003): changing riverbed morphology Gohagram to Sungutgola
The map shows changes in the river between 1854 and 2003.
Data source: The map drawn from the Survey of India (SOI) maps (73M/11, 12, 1: 63,360, 1: 50,000), and 2003 LISS-3 scenes of IRS-ID satellite is shown. Map of the country adjacent to the lower parts of the Damoodah and Dalkissor rivers prepared by Captain Dickens, C.H., 1854, Calcutta, at scale 1: 126,720 has been consulted

correspond very well in the lower section. The considerable variation in the upper reach speaks of a non-graded profile (Sen 1993). Construction of a reservoir in the river reduces the sediment supply downstream, and changes in the fluvial processes should tend to reduce the sediment transport capacity in order to re-establish the equilibrium. According to Mackin's (1948) concept, the slope should be flattened considerably following the dam construction and the whole process would proceed downstream at a slow rate (Mackin 1948; Chien 1985).

Another parameter studied by Sen (1978) for some cross-sections of the Damodar River is the width-to-depth ratio, a measure of the efficiency of the channel. This ratio is one of the best measures of channel conveyance characteristics. This study observed that the river channel ratio is found to have a wide range and never satisfactorily shows perfect channel efficiency. Below the Durgapur Barrage the heavy sedimentation features are conspicuous, the cross-section being of a shallow saucer shape with sandy waste and showing the formation of a number of secondary channels. Here the width-to-depth ratio mostly exceeds 40, which indicates the impotency of the channel where it is presumed to act as a sediment sink. Flushing dozes have been proposed for Damodar River (DVC V-1) but were never properly implemented due to the occupation of the riverbed by people.

4.8 Stabilization of Bars

As we have discussed in previous sections, enormous sand loads carried by the Damodar have given rise to sandbars within the river channel. It is reported that a large tract of accreted land, a few kilometers upstream of Barddhaman, was assessed and settled in 1842 (Ricketts 1853). These lands were probably formed in the devastating flood of 1840 which had a peak flow of 18,129 m^3/s at Raniganj. From the map surveyed in 1854 by Captain C. H. Dickens (1853), it is found that two sandbars had emerged a little above Barddhaman near Belkas and near Jujuti. Near Bhasapur there was a semi-transient mid-channel bar covered with grass jungle and known as *Baseepoor* (Fig. 4.16) which means it was inundation-prone. In the same period, near Jujuti and Belkas and in Gaitanpur, sandbars were semi-mobile marginal bars.

The maximum flood recorded in the pre-dam period occurred from August 6 to 12, 1913, and lasted for about 123 h. Its peak-flow of 18,408 m^3/s was observed at Raniganj. During this flood, the majority of water flowed out from the river banks and into the surrounding areas. About 4,474 m^3/s passed through the breaches in the left embankment through the town of Barddhaman and into the Hooghly River by the Banka Nadi. About 435 m^3/s went through the breaches in the left bank embankment further downstream and entered the Hooghly River near Uluberia. About 11,328 m^3/s spilled over the right bank above and below Barddhaman and found its way into the Bakshi basin of the Rupnarayan River. Only the remaining 1,416 m^3/s passed through the main channel. In such a flood the river carried enormous quantities of sand but maintained a relatively small amount of discharge. Additionally, the main river channel was unable to scour out and maintain a single adequate channel to carry the suspended sediment load. The sands were deposited along the riverbed when the current entered the flat country below Raniganj, forming a series of migratory sandbars as is evident from the map (SOI) surveyed in 1929–1930.

Increasingly, large floods were shown to modify the location and size of the sand bars along this river stretch. This can be shown from the impacts of the floods in 1935 and 1943 at Raniganj, both of which were substantially larger than the flood of 1929–1930 (Hart 1956). In 1929–1930 there were 35 migratory sandbars, all covered with xerophytic type of bushes and grasses. After the 1935 and 1943 floods, many sandbars migrated downstream, some of them merging together to form elongated bars, while others became fragmented. From the mouza maps surveyed in 1954–1957 it appears that some of the bars had acquired a definite shape. From 1947 onwards, after the partition of India and the former East Pakistan (the present Bangladesh), refugees from Bangladesh began to occupy the sand bars which have continued to be impacted by human interference to the present day. 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. From the survey of Indian topographical sheets (1969–1974) it is observed that some sandbars have merged with the mainland and most of the sandbars are settled. From the topographical sheets surveyed in 1985–1986, 2003 LISS-3 scenes of an IRS-ID satellite image and 2007–2008 field survey, it is evident that some new sandbars have emerged and some have been destroyed. Formation of sandbars together with channel migration characterizes the Damodar riverbed. Today these sandbars support a population of over 50,000 people.

4.9 An Example of the Rate of Changes to the Channel Sandbars

The rate of changes to channel bar for Bara mana are shown (Table 4.17).

Table 4.17 Changes rates to channel bars

Changes in Sandbar Areas, Bara Mana (in km^2)

1920	1957	1996	2003	Net change (1920–2003)
9.4	9.71	9.981	10.244	0.844

Rates in changes in Baramana

Period	Net change (km^2)	Rate of change (km^2/year)
1920–1957 (37 years)	0.31	0.008
1957–1996 (39 years)	0.271	0.007
1996–2003 (7 years)	0.263	0.038
1920–2003 (83 years)	0.844	0.0102

Computed by the author.

4.10 Shifting Bank Lines and Bank Erosion

Bank erosion poses a serious problem along the Damodar and its distributary channels of which Sen (1991) cites several examples. In the years between 1881 and 1956, valley side slopes at Jamalpur near the bifurcation point retreated by 94.49 and 30.48 m on the right and left bank respectively. This indicates an average rate of retreat of about 1.34 and 0.43 m/year respectively. Valley widening also occurred in different places along the Damodar River and the width of the river has increased in different places and at different rates. Shifting bank lines and bank erosion have become a problem upstream of the Durgapur barrage near Andal and between Shrirampur and Kalinagar near Barddhaman (Figs. 3.10, 3.11, 3.12). Sand quarrying from the riverbed also exacerbated the problem.

Bank erosion is also a serious problem just below the Durgapur Barrage. A series of indigenous cross-dykes or dams have been placed below the Barrage to protect the sand bars from erosion. These have generally been unsuccessful as shown in a typical example in a sandbar below the Durgapur Barrage. An indigenous cross dyke or dam exists at Rangamatia and is locally known as the Rangamatia dyke. The main purpose of this dyke is to divert the flow coming from the Durgapur barrage away from the South Rangamatia sandbar. The villagers have constructed a series of dykes afterwards to create an obstruction to flows coming through the barrage during the monsoon period. Some of these dykes were destroyed during later periods after the passing of peak flows. It is too early, however, to comment on the effects of these measures.

4.11 Present Condition of the Jamalpur Regulator

With the closure of the dead river Kana (i.e., a distributary of the Damodar) in 1863, the Jamalpur regulator was opened on the Kana Damodar in 1875. This became the only leeway for flood water on the left bank and was 4.57 m wide and 0.91 m deep. Willcocks observed that its bed height prevented it from taking low water and official regulations prevented it from taking high water. It ran for only 2 days in 1927 and 8 days in 1929 (Willcocks 1930). This ill-conceived regulator does not have any function at present (Bhattacharyya 1998).

4.12 Present Condition of Jujuti Sluice and Eden Canal

The Banka Nadi and the Damodar River are connected at Jujuti. Here a sluice and feeding channel were constructed to admit water from the parent channel to the Banka Nadi and from there to the Eden canal which was supposed to feed the Gangur, Isura and Saraswati Rivers. The design of the Eden canal, however, was inadequate for this purpose. The 1855 flood created a breach 107 m wide on the embankment of the Damodar River. The Eden canal was designed to control only as much water as the Banka Nadi was able to carry in its peak flow period (Biswas and Bardhan 1975). Initially the Banka Nadi was able to carry its run-off discharge without causing any drainage congestion in its course. Over time, however, its carrying capacity deteriorated due to the increased silting of its riverbed. This situation was worsened by the introduction of silt-laden Damodar river water to the Banka river, via the Jujuti and Jhapur sluices, for the purpose of supplying water to the Eden canal system (Sen 1976). Nothing has been done so far to remove these heavy silt deposits from the riverbed. Because the Banka Nadi would historically inundate adjacent low-lying areas during high discharge conditions, all the gates of the Jujuti sluice have been closed by sandbags, making the sluice totally inactive. Sand deposits made by the introduction of Damodar river water have also cut off the water supply to the Banka Nadi during the monsoon season.

Apart from the Jujuti sluice, many other sluices were built on the Damodar River to keep water levels well below the crest of its embankments. The surplus water during floods could be passed through these sluices and drained by several small streams to the nearby Hooghly River. This protected the whole country from inundation and supplied the parched soil with water for agriculture. This also reduced the death rate from malaria (Bannerjee 1943). All of the sluices on the left bank are now in precarious condition and sand banks have cut off the supply from the Damodar River to the left bank.

The goal of using the Eden canal for navigation remains unfulfilled. This is not surprising for several reasons. First, an environment which inhibits productive activity also inhibits movement of produce. Secondly, and more specifically, in a waterway influenced by seasonality of supply, navigation and irrigation have opposing claims. An efficient irrigation canal is supposed to run through the highest portion of the territory to be irrigated, to have a shallow depth, to collect water from the higher reaches of the river during the high water period, and to empty itself by releasing the water at a period when the general supply falls short of the requirement. On the other hand, an efficient navigation canal is supposed to run through low-lying tracts in order to gather as much water as possible during peak seasons, to have considerable depth to allow movement of boats, and to hold back the water within the canal when the general supply is small. Any attempt to combine the two is overwhelmingly likely to end in failure (Biswas and Bardhan 1975).

4.13 Present Condition of the Ulughata Sluice

Paucity of data makes it difficult to assess the Ulughata Sluice, the most recently constructed control structure on the lower part of the Lower Damodar. It has been observed, though, that whenever the Hooghly river water level rises there is a backrush of water into the Amta channel (Fig. 2.1). This has helped to revive a section of the Amta channel and the excess water is used for irrigation. Below the Ulughata Sluice, however, the channel has deteriorated noticeably to the extent that it has now been declared “a defunct channel” by the Irrigation and Waterways Department, West Bengal. The sandbars in the defunct section have become immobile and the thalweg looks like a nala (small rivulet), which at places is fordable almost throughout the year except in the monsoon season or during high tides (Bhattacharyya 1998).

4.14 Summary

The hydro-geomorphic consequences of transverse control structures on the culturally defined Lower Damodar may be summarized as follows:

i. The Jamalpur regulator no longer functions and the Jujuti sluice has been plugged with sandbags. Hence, these two control structures have lost their significance. The initial planning of the Eden canal seems to be defective as it failed to serve the twin purposes of irrigation and navigation. On the other hand, it has been connected with the DVC left bank main canal and the combined flow has revived some of the decaying distributaries of the Damodar.
ii Part of the Amta channel has been improved due to the backrush of water from the Hooghly into the channel after the construction of the Ulughata sluice. Below the Ulughata sluice, the channel appears to be a defunct one.
iii Monsoon discharge below the Durgapur barrage and the Rhondia weir has decreased but there is more release of water during the non-monsoon period for irrigation purposes.
iv. Frequency and magnitude of peak flow have decreased and the peak discharge has shifted from July–August to late September–October.
v. Return period of flood of bankfull capacity has increased from 2-year in the pre-dam to 14-year in the post-dam period. In the river, 13,276 m^3/s, a 10-year flood for the pre-dam period, has been reduced to 6,584 m^3/s flood, a reduction of about a half, a 5-year flood has been reduced from 11,095 to 5,258 m^3/s and a 2-year flood from 7,800 to 3,255 m^3/s with a reduction of 53 and 58% respectively.
vi. Under very high rainfall conditions the Panchet and the Maithon Dams are forced to release excess water. This creates drainage congestion in the lowermost part of the Damodar when the ground water table rises significantly in excess rainfall years.
vii. From 1857 to 1917 there were 33 floods with a magnitude between 5,664 and 8,496 m^3/s. In the later periods, this number was reduced to 11 (1933–1956) and 5 (1959–2007). The number of floods with a magnitude between 2,472 and 5,664 m^3/s has increased from 4 in the pre-dam period to 25 in the post-dam period (Table 3.3).
viii. In the pre-dam period the suspended load was higher than that of the post-dam period. The relation between suspended load and discharge is positive but not high due to trapping of sediments in the reservoirs.
ix. The riverbed is characterized by sandbars, point bars and gutter channels. Near the bifurcation point, there is a reverse slope. Alluvial bars are less transient now.
x. Sinuosity index has increased. Channel length has increased due to the increased sinuosity index. Shifting of bank lines and bank erosion are observed mainly on the left bank side.

Landforms and associated processes are genetically classified as endogentic and exogentic. River control structures, major or minor, are anthropogenic landforms now acknowledged as belonging to the genera of exogenetic landforms. The status and designation of geomorphic forms, processes, and materials that have undergone changes due to these anthropogenic interventions in a fluvial system are really unknown even now. Stream flow, riverbed sedimentation, bank erosion and similar processes are always governed by universal physical laws or natural laws. Humans as geological agents can only modify the flow pattern by controlled release of water from a reservoir but the stream flow itself, whether laminar or trubulent, is controlled by a fluid mechanism. Similarly, humans can accelerate or reduce sedimentation and even change the locale of this process by deliberate attempts but cannot change the principles of vertical and/or lateral accretion. Critical tractive force, stream competence, and capacity are all controlled by physical laws. The same physical laws operate in a natural as well as in a reservoir channel and the river control structures cannot change them. As noted by Leopold et al. (1964), geomorphic effects produced by humans are, as a rule, the same as those produced without human intervention. The human role is generally to modify some variables in the system.

Although products of economic and social demands, river control structures have profound influence on the flow regime alteration, channel modification and riverbed sedimentation (Williams and Wolman 1984; Church 1995; Bhattacharyya 1998, 2009; Graf 2006; Grantham et al. 2008). In the case of the Lower Damodar, flow regime, flood behavior, and channel morphology has changed remarkably, particularly within few decades of dam closure, and these changes have followed hydro-geomorphic principles as well as economic and social principles.

The foregoing analysis shows that geomorphic forms and processes should be placed in a separate category in the genetic and/or generic classifications of forms and processes. They should be designated as “quasi-natural” forms and processes. They are natural, as they follow natural laws, but they have been modified by human-made structures and human action; therefore, they are quasi-natural and human-modified in character (Bhattacharyya 1998).

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Chapter 5
Colonization Processes on the Lower Damodar Riverbed

Abstract The Damodar riverbed has been colonized in different phases since 1947, mostly by Bangladeshi refugees. They are self-alienated refugees who have rejected the dole-sustained existence in government-sponsored refugee camps and opted, instead, for life on the controlled riverbed. After India achieved independence in 1947, fuller utilization of the river resources was needed to solve socio-economic problems. At the same time, the partition of India initiated large scale migration, particularly of Hindus from both West and East Pakistan (Present Bangladesh). Of all the refugee-receiving states in India, West Bengal had the maximum number of refugees, a problem that was aggravated after the Bangladesh War of 1970 when there was a fresh influx of refugees from independent Bangladesh. In both phases, a significant number of Bangladeshi refugees selected the riverbeds of West Bengal as their second home. The Lower Damodar bed is one such riverbed. It has been permanently occupied by these Bangladeshi refugees and has become a major resource base for them. The flood of September 1978 also initiated a desperate migration of locals from the flood-affected areas of Medinipur and Hooghly districts to the adjacent riverine sandbars. Control structures on the river have brought many changes to the riverbed environment and the refugees are constantly struggling with this changed environment for their survival.

Keywords Bangladeshi refugees · Control structures · Decolonization · Resource base · Riverbed environment · Self-alienated

5.1 History of Colonization

Voluntary migration, including labor migration and its socio-economic significance, has received much attention from social scientists all over the world. In comparison, involuntary migration has failed to draw similar notice, although involuntary or refugee migrations have greatly increased in magnitude since the Second World War.

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Europe had to deal with refugees after the Second World War; the Third World has faced refugee problems from the early post-World War II years (Rogge 1987). In the developing countries, e.g., in India, the problem of refugees started mainly with the process of decolonization. Decolonization and the partitioning of India in 1947 unleashed a refugee problem that has yet to be solved.

In the area under study, the Lower Damodar riverbed is occupied mostly by Bangladeshi refugees (Plates 5.1a, b and 5.2a–c). In the next section we will gauge to what extent these refugees have applied geomorphological knowledge to assess resource potentialities and hazard risks of the riverbed between control structures. What is noteworthy here is that the decolonization of India necessitated the fuller utilization of the river resources to solve the socio-economic problems of an emergent independent nation; at the same time, the partition of India initiated large scale migration, particularly that of Hindus from both West and East Pakistan (the present Bangladesh). Of all the refugee-receiving states in India, West Bengal had the maximum number of refugees and this problem was aggravated just after the Bangladesh War of 1970 when there was a fresh influx of refugees from independent Bangladesh. In both phases, a significant number of Bangladeshi Hindu refugees selected the riverbeds of West Bengal Rivers as their second home. Thus, the riverbed of the controlled Lower Damodar has been occupied by Bangladeshi refugees since 1947 and has become a major resource base for them. The problem of resettlement of refugees has become an applied geomorphological issue because of this functional relationship between refugees and riverbeds.

The objectives of this section are to trace: (i) the phases of colonization in the riverbed of the Lower Damodar, (ii) the causes of colonization, (iii) the socio-economic background of the colonizers. The method is ideographic and the structure of argument is inductive. The spatial scale is the riverbed and the time span extends from 1854 to 2008. There is a paucity of data on the riverbed population as most of the settlements were designated as forcibly occupied settlements until recently. The only alternative was to collect primary data from field survey through repeated field visits. Apart from their socio-economic significance, refugee concerns are sensitive political issues. This posed a serious problem during the earlier period of field survey.

5.2 Background of Refugee Influx

Decolonization, the partition of India in 1947, and unfortunate riots at different times are the origins of the diaspora of Bengali Hindu refugees in West Bengal. The first phase of Bengali evacuation probably started after the Noakhali riots in 1946 (Chakrabarti 1990). The second and most significant phase started just after the partition of India in 1947. Between 1947 and 1952, millions of Bengalis, along with a sizable number of non-Bengalis, migrated from the erstwhile East Pakistan (present Bangladesh) looking for work. The number of migrants swelled until 1958 (Bhattacharyya 1998).

In order to trace the phases of refugee influx, the policy adopted by the West Bengal government must be mentioned here. Refugees were classified as “old migrant” if they had come between 1946 and 1958, “in-between migrants” if they had migrated between 1958 and 1963, and “new migrants” if they had crossed the border after 1963. Unlike “old migrants” the “in-between migrants” were not eligible for any assistance for rehabilitation. The “new migrants” were eligible for rehabilitation benefits if they had opted for resettlement outside the state of West Bengal (Chakrabarti 1990). This policy was adopted to discourage large numbers of immigrants but the problem is difficult to solve and has taken on a new dimension since the Bangladesh War of 1970.

At all phases of migration people came mostly from the farm sector. Although they were provided with accommodation and food in government-sponsored refugee camps and colonies in West Bengal as well as in other states such as Orissa and Madhya Pradesh, the job opportunities were extremely limited as the farm sector of West Bengal was already saturated. A sizable number of refugees rejected this dole-sustained existence and went in search of self-sought settlements where they could enjoy social, economic and a kind of political independence. Searching for a new “niche” was the beginning of riverbed colonization in West Bengal (Fig. 5.1).

5.3 Phases of Colonization in the Lower Damodar Riverbed

5.3.1 The First Phase of Colonization

Most of the riverbed settlements in the Lower Damodar are refugee settlements, but colonization started long before 1946–1947. The studied section is a part of the Ranigunj coalfield above Durgapur and coal seams are exposed along river courses. Hunter’s report (1877) states that coal was known to exist in this part of present Barddhaman district as early as 1774 but commercial mining activity probably started around 1777. By 1820 open pit mining started in the Ranigunj coalfield and from 1830 onwards several collieries were opened (Hunter 1877). Opening of coalmines initiated a phase of voluntary labor migration from the Chhotanagpur plateau to this part of Bengal. It merits mention here that labor migration from Bihar in the colonial era was very common. Unskilled but sturdy and trustworthy Bihari laborers were required to clear forests, to remove over-burdens in collieries, and to work as helpers for the construction of buildings, roads, and railways, and as laborer in factories. They were also appointed as gatekeepers and village policemen by local landlords and kings. Thus, Biharis, including Bihari tribes, were significant constituents of the population of undivided Bengal. This population characteristic has not lost its relevance in independent India.

Colonization in Gangtikali, the first Bihari-settled riverine bar, is closely linked with erstwhile collieries (though abandoned now), which existed until 1958. From the statements provided by the settlers, it may be assumed that colonization probably started in the latter part of the nineteenth century and the present Biharis belong to

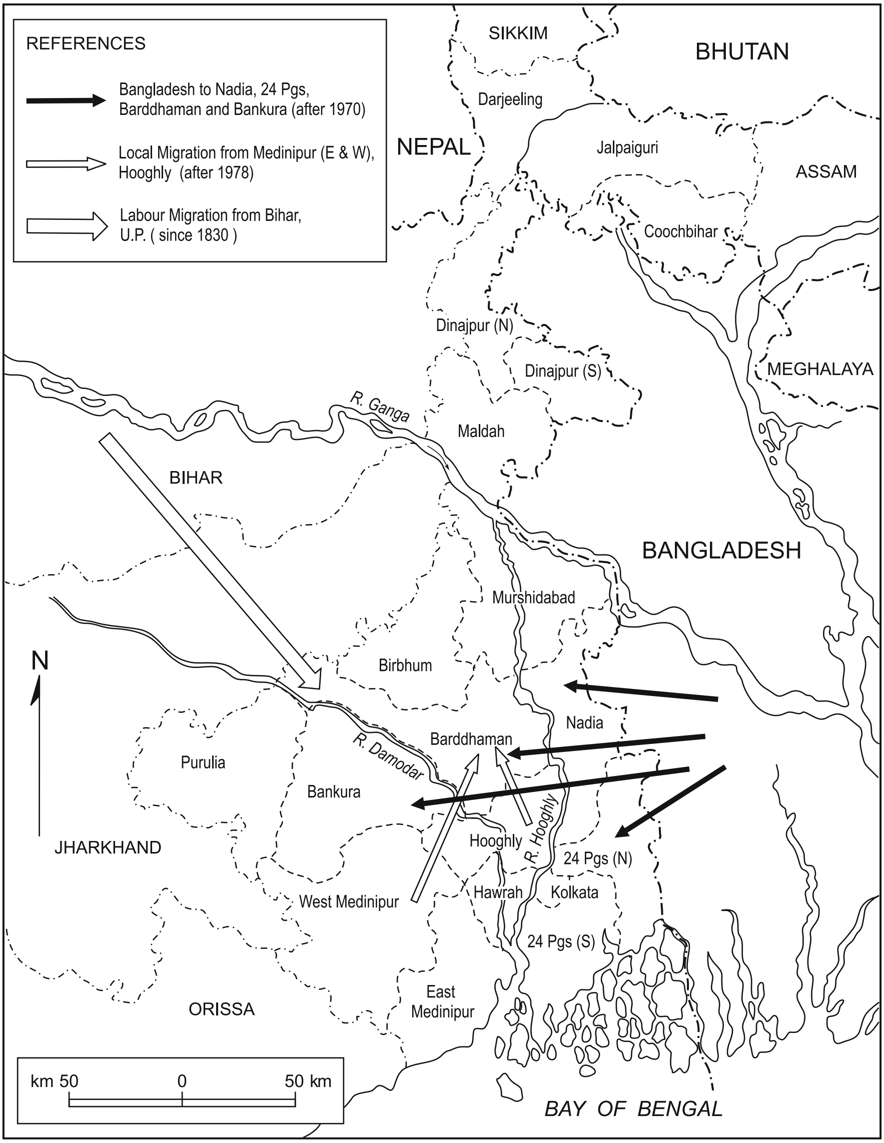

Fig. 5.1 Migration route to lower Damodar river bed

the third generation (Fig. 5.2). Gaitanpur, a riverine alluvial bar near Barddhaman, has a sizable number of Biharis. They used to work under the Barddhaman Raj; later, with the cessation of the Raj, they were granted lands in Gaitanpur. Thus the first phase of colonization in the riverbed of the Lower Damodar was initiated by inland labor migration from Bihar. They may also be referred to as “economic evacuees”.

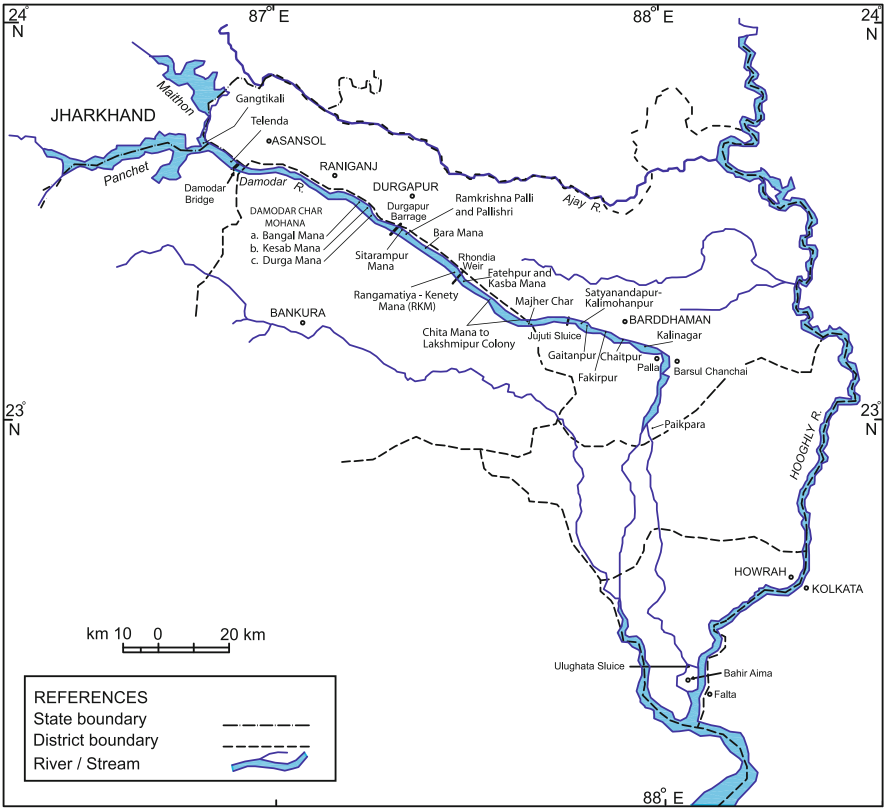

Fig. 5.2 Distribution of Damodar sandbars or char lands

Paikpara, just above the Amta Channel, was a part of the Damodar riparian tract but not a part of the riverbed itself. With of the opening the Muchi-Begua hanas, since 1865 it appears to be an alluvial mid-channel bar. In the map of Dickens (1854), Paikpara (previous Panchpara) has been mentioned as an old settlement (Fig. 3.8). This settlement dates back to 1854 pre-dating India's independence. Harogobindapur and some other settlements have attained the status of riverbed settlements after the construction of the left bank embankments. Like Paikpara, they are colonized by local Bengalis. All the settlements mentioned above belong to the first phase of colonization of the Damodar riverbed (Bhattacharyya 1998, 1999).

5.3.2 The Second Phase of Colonization

Significant colonization of the riverbeds of West Bengal from north to south and from west to east started just after the partition of India. This is the beginning of involuntary migration of political refugees. Most of them are Bengali Hindus, although Biharis who were economic evacuees in undivided Bengal also came to India with the refugee influx and started occupying the riverine bars. Their number in the Lower Damodar bed may be small but Bihari culture has left its imprint on the landscape emerging out of specific land use practices. River-retreat land use was common among locals in some parts of the Lower Damodar but colonization in the riverbed was initiated by the refugees.

The first tract selected for settlement was the reach between Durgapur barrage and Jujuti sluice. A wide riverbed with less mobile alluvial bars covered with grass jungles was seen as a favorable location for colonization in the riverbed. Also, unwarranted flood risks have been reduced due to water retention behind the Durgapur barrage and the Panchet reservoir. Thirdly, controlled release of water with prior warning and release of water through definite channels were other favorable factors. There was also a noteworthy socio-political factor. The refugees who fled from government-sponsored camps and colonies and those who were in the category of "in-between migrants" or "new migrants" preferred to stay away from the main influx stream and remain unidentified. They opted for a location away from main transport routes and urban centers. The very locational disadvantage was one of the factors as to why the refugee-settled sandbars are away from Barddhaman. The most prosperous settlement, the Bara Mana is so located (Bhattacharyya 1998, 1999–2000b). Gradually other parts of the Lower Damodar bed were occupied by the Bengali and Bihari Hindu refugees (Fig. 5.2).

5.3.3 The Third Phase of Colonization

A riot in erstwhile East Pakistan initiated a fresh flood of Bengali refugees to West Bengal but this phase is not well-recorded in government reports. The actual third phase of immigration and consequent riverbed colonization began during the Bangladesh war and the liberation of Bangladesh in 1971. As the eastern border is neither well-defined nor well-guarded, millions again crossed the border. The established refugee clusters in the Damodar riverbed colonies were extended.

The reach between Rhondia weir and Jujuti sluice was settled first. Majher Char, Lakshmipur, Fatehpur and Kasba Mana are located in this section. The second phase was initiated by the Durgapur barrage, where below-barrage colonization began after 1958 although there were scattered hamlets before, such as Bara Mana, Rangamatia, Kenety Mana, Ramkrishna Palli, Pallishri, and Sitarampur Mana. Colonization began rather late above the Durgapur barrage. Telenda Mana and Damodar Char Mohana are rather new entrants in the colonization history of the Lower Damodar riverbed (Fig. 5.2).

5.3.4 The Fourth Phase of Colonization

The September flood of 1978 initiated a desperate migration of locals from the flood-affected areas of Medinipur and Hooghly districts to the adjacent riverine bars. The local people purchased land from the refugees and have set up new colonies in

Rangamatia, Fatehpur and Kasba Mana. Flood-distress, generating local migration from nearby flood-prone districts, is an ongoing phenomenon. Thus the riverbed population is constantly on the rise.

5.4 Summary

i. The first phase of riverbed colonization started with inland voluntary labor migration from the Chhotanagpur plateau to the Ranigunj collieries
ii. The second phase was initiated by decolonization, the partition of India in 1947, and post-partition riots
iii. The third phase is marked by the Bangladesh War of 1970
iv. The September flood of 1978 initiated the fourth phase of in-migration from flood-affected areas
v. In India, the Bengali evacuees were majority-identified or political refugees, while in the self-sought settlements they can be seen as self-alienated refugees (Kuper and Kuper 1995; Bhattacharyya 1998).

These phases of colonization and self-alienation in the self-sought settlements have explicitly influenced riverbed land utilization and flood plain zoning in the Lower Damodar River. Between Maithon/Panchet reservoirs and the Falta outfall, there are approximately 23 mid-channel sandbars or char lands and a series of point bars. Alternate point bars with a narrow channel are the primary characteristics of the riverbed below Barsul-Chanchai. Intensive field work has been done in these sandbars. A detailed perception study has been carried out to get a better view of the human role in changing fluvial system and of human perception, adaptability, and resource evaluation in the river bed.

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Chapter 6
The Controlled Lower Damodar River: A Social Perspective

Abstract The Damodar riverbed consists of a series of alluvial bars that are now used as a resource base mostly by refugees. The stretch between Panchet Maithon reservoirs and Barsul-Chanchai is not atypical in terms of contemporary riverbed morphology and bed materials particularly below the Durgapur barrage. But the riverbed landscape, formed by interactions between the riverbed and its occupiers, shows diversity at a micro level. Using their knowledge of river stages, settlers have matched land use at fine scales to flood incidence, applying a concept of flood zoning to the riverbed and effectively utilizing every available inch of space. Functional relations between the riverine environment and riparian community have been influenced by culture, social space, perceived environment, land ownership rights and political forces. As there is no a priori model for human-environment relations, assessment of short-term risks and long-term benefits of water release from the reservoirs and decisions on specific land use are made on the basis of personal experience. The stretch between Maithon/Panchet reservoirs and Barsul Chanchai has become less hazardous and more resource-rich with the mitigation of the annual flood discharge. Here risk is capitalized as resource and long term benefits have overshadowed the short term risk. Paikpara is an example of changing location of the resource base subsequent to a geomorphic threshold. The opening of the Muchi-Begua Hana has transformed an over-bank settlement to a mid-channel settlement. The thalweg of the Amta Channel is extremely narrow compared to the culturally defined riverbed and is not so significant in comparison to the other two sectors of the Lower Damodar.

Keywords Flood-zoning · Functional relations · Indigenous techniques · Land-use · Perception · Resource base

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6.1 Understanding Human Role in Changing Riverine Environment

While examining the applied geomorphological issues of the Lower Damodar, the focus was on floods, flood control measures, and the impact of control structures on selected hydro-geomorphic parameters. Geomorphic forms, processes and materials between control structures, lateral or transverse, were considered quasi-natural but fundamental entities and were explained accordingly. In the present section, the controlled riverbed will be assessed from a land use and social perspective since a large portion of the riverbed is intensively used by Bangladeshi refugees who have colonized the riverbed in phases. They have taken an active role here in changing the riverine environment through land utilization. The occupiers have built up a functional relationship with the riverbed. Land use in the riverbed bears the imprint of the functional relationship between the riverbed and its occupiers. As a result, the forms, processes and materials in the riverbed are no longer fundamental entities but deserve functional identity. This does not necessarily imply that land use characteristics are totally governed by riverbed characteristics of the controlled sector. People's culture, perceptual capacity to assess an environment and position in society also play a decisive role in decision-making regarding specific land use. Ownership of land, demand and market forces are also significant factors behind land use decisions (Bhattacharyya 1998, 2002, 2009).

It has been accepted now that cultural elements such as settlements, agricultural fields, roads and railways are viable components and effective indicators of a dynamic geomorphic landscape. One may still argue that different artifacts are nothing but mere components of cultural landscape. The validity of this statement is not questioned but is worth further consideration. A cultural landscape results from human intervention with the physical landscape through specific culture and, ultimately, components of the inherited physical landscape become inseparable from the superposed components of cultural landscape. V. R. Savage (1992) has traced the changing landscape of Singapore with the changing of land use. His article has been included in "Physical Adjustments in a Changing Landscape" edited by Gupta and Pitts (1992). Land utilization in the Damodar riverine sandbars has been treated as an anthropogenic geomorphic process and the emergent landscape as a product of twin processes, hydro-geomorphic and anthropogenic. Factors that play into riverbed land use include tension between host communities and the migrants over a shared resource base and the fact that an active river remains flood-prone despite flood control measures.

River training is an anthropogenic process but this process has to function within the limits of natural laws. In land utilization processes, however, non-physical laws and norms have to be acknowledged to a greater extent together with physical forces. Cultural heritage, socio-economic situations, and technological levels are the significant factors in rural land use. Variations in physical aspects bring explainable changes in land use under similar geomorphic processes and other correlated environmental parameters (Verstappen 1983). But unlike physical laws, social or economic laws and norms are not universal but location- and culture-specific. Applied geomorphological issues are also location specific (Pitty 1982; Bhattacharyya 1998). Therefore, in the analysis of land use, the method has to be ideographic.

The spatial range considered in this study is the riverbed between and/or below control structures on the river Damodar. Almost all riverine bars have been considered between Panchet and Maithon reservoir and the Falta outfall for land use analysis. The whole stretch has been divided into three sectors. Sector one extends between the reservoirs (Maithon and Panchet) and Barsul-Chanchai village, where the Lower Damodar takes a southerly course. Sector two stretches up to Paikpara settlement below, where the Damodar starts distributing its major part of discharge through the Kanki-Mundeswari. The Amta channel has been treated separately. The time span of the study is from 1990 to 2008 in assessing human perception, adaptability, land-use characteristics, and evaluating resources in the riverbed. The background of the present land use, however, has been traced from 1854 since the Dickens's map has been used as a base map for this purpose.

In examining riverbed land use in the Lower Damodar, hydro-geomorphic data from previous sections have been used and conclusions of the previous sections are the foundation blocks on which the basic structure of arguments for and against contemporary land use has been built for the present chapter.

The technique adopted is the field survey technique. The perception survey technique has also been applied to assess people's views on the control structures, consequent hydro-geomorphic changes, resource potential of alluvial bars and hazard risks in between control structures. Interpretation of a series of cadastral maps, SOI (Survey of India) maps, geocoded maps, and satellite images is the geographic technique and this technique has been applied to generate qualified data to be incorporated with active field data and hydro-geomorphological data for appraisal of land use. Tools include SOI maps, cadastral or mouza (a land-settlement division of an area) maps, the 1994 Satellite Image (IRS-IB LISS-2/FCC/classified image, 1:100,000) and IRS Geocoded Imagery of 1992 and 1999 (1:50,000) and 2003 LISS-3 scenes of an IRS-ID satellite (Appendix A). Some sociological, anthropological and economic and geographic concepts like social space, culture, perception, resource, human ecology, hazard, political economy, empiricism etc., will be considered while examining the land use characteristics. Like any other applied discipline, applied geomorphology also takes an interdisciplinary approach, and therefore can borrow relevant concepts from other disciplines.

Land use data has been collected from repeated field visits. I have had to depend on active data since rural land record offices maintain land use data only for legally owned land. In my study area, the refugees have either not yet obtained "patta" or land deeds, or they have only been granted land deeds in the riverine alluvial bars very recently. Therefore, the BDO or Panchayet, BLRO or similar institutions do not have complete sets of land use data. Most of the Bangladeshi refugees have been granted land deeds. They were very much apprehensive about the research objectives and were initially reluctant to provide data on land area and crop production.

Colonized people were surveyed in groups and individually. The first reconnaissance survey and actual survey started in 1990 and 1993 respectively and was completed in 1997 with follow-up surveys conducted in 2000, 2001, 2007, and 2008. The total number of sandbars surveyed in the Damodar River is 23. Each sandbar consists of several mouzas that include 91 villages. The total population of these sandbars is 50,000 approximately and 1% of them were surveyed initially using the model questionnaire.

The main questions addressed are given in the survey questionnaire (Appendix H), and some of their answers in Bengali language are as follows:

1. Can you assess how much area will be inundated if water is released from the reservoirs?

We estimate accurately that peripheral areas of sandbars get inundated with discharge exceeding 4,248 m^3/s, multiple crop areas are flooded with discharge exceeding 5,664 m^3/s, and we need to take shelter on the highest part of the Bara Mana situated within northeastern part of the Pakhanna-Bhairabpur mouza with streamflow exceeding 7,080 m^3/s.

"Amra jodi sathik vabe hisheb kori tahole dekhbo 1.5 lukh cusec er beshi jal charlei balicharer prantobhag bheshe jabe, 2 lukh cusec er beshi jal charle bibidho shasya utpadaner khetragulo o bheshe jabe, ar jodi 2.5 lukh cusec er beshi jal chhare amader Pakhhnna – Bhairabpur mouzar uttarpurbo dike bara manar sabcheye unchu jaygay giye ashray nite hoy" said Prakash Biswas, a farmer of Bara Mana.

1. What is your experience when water is released from the reservoirs?

Release of water from reservoirs has initiated bank erosion and we are constructing a series of dykes to fight against bank erosion.

"Nadirparer kshoy shuru hoy jaladhar theke jal chara thekei ar amra ai parer kshoy rodh koear jonno band her par bandh banie cholechi" said Binod Das, a well-known farmer, who took initiative for planning and constructing a series of dykes in Rangamatia.

I also asked several questions as follows:

i. Can riverbed occupiers perceive hydro-geomorphological consequences of control structures?
ii. Are they aware of regular or sudden release of water from reservoir, barrage, and weirs?
iii. What are the indicators selected by them for assessment of resource potentialities of the riverbed?
iv. What are the measures taken during flood years, or if there is a threat from sudden release of water or bank erosion?
v. Are the Bangladeshi migrant communities aware of their refugee status? Does that influence their decision on land use?
vi. Is there any difference in land use between locals and non-locals, particularly between local Bengalis and Bangladeshi refugees?
vii. Is there any political pressure on the refugees regarding land use?

6.2 Contemporary Riverbed Characteristics Between the Maithon Panchet Reservoirs and Barsul-Chanchai

The Lower Damodar between the reservoirs and the Barsul-Chanchai settlements flows through two disparate phases. Right up to Raniganj, the most important colliery town in the district of Barddhaman, the riverbed and bank are characterized by the features of a bedrock-controlled river. Just below the reservoir, there is a rocky exposure. Similar rock outcrops are to be observed near Dhanua, Bakulia, Babjadanga, and Amkula above Raniganj. The exposed rocks belong to the Gondwana Sedimentaries. Height of the river bank varies between 6 and 10 m between the reservoir and the Radhanagore railway station near Sitarampur. Below Raniganj, the Lower Damodar bed is an alluvial controlled riverbed. The river bank height varies between 2 and 4 m except in a few places. Below Barddhaman, river bank height exceeds 4 m only for a small section. In the bedrock-controlled sector there are several bars of differential locations, shapes and dimensions. Bar materials are usually coarse sand together with fragmented sandstone, shale and coal. Below Raniganj, the riverine bars change their characteristics with the changes becoming more noticeable below the Durgapur barrage. Several longitudinal bars, either mid-channel or marginal, are observed below the barrage. The bar materials become finer and are usually sandy loam, loam or clay. Between the reservoirs and the Durgapur barrage, the Lower Damodar is deep enough for all-season ferry services. But below the Durgapur barrage ferry service is restricted to the monsoon season only and the river is fordable in the non-monsoon period (Plate 6.1).

Major left and right bank tributaries are the Harial, Nunia, Singarani, Tamla, and Kukua on the left, and Machkanda, Beharinath, Bangarpur, Ghaighata, Chouphari, Barajuri, Barjara, and Sali on the right. These tributaries flow through erosion-prone deforested tracts in the Raniganj coalfield and soil-covered Purulia and Bankura districts and contribute an enormous amount of sediment to the Damodar above Silna. Of these tributaries, the Sali on the right and the Nunia nala on the left need special mention. During the 1978 floods, the Sali was almost choked with sediment in its middle and lower sectors and contributed enormous amounts of sediment to the Damodar River. The riverbed sediments are also derived from sheet wash, particularly in colliery areas where soil has been loosened due to mine blasting. Coal spoils contribute sediment to the riverbed through sheet wash and gully erosion as well. The shallow riverbed below the Durgapur barrage is dotted with several semi-stationary and stationary alluvial bars. There are several spill channels or *hanas* to be observed in this area. These have been mentioned in the previous section. Khari and Banka were two important distributaries in the historical past but have now been severed from the main river due to construction of roads, railway lines and embankments.

Above Raniganj, Gangtikali is the only settlement in a riverine bar. The number of riverbed settlements increases below Raniganj and multiplies below the Durgapur barrage right up to Barddhaman. Between Majher Char and Barsul-Chanchai, the river narrows down and the number of alluvial bars decreases. From a riverbed utilization point of view, the section between the Durgapur barrage and the Jujuti sluice is the most significant. There are several settled and few partially settled sandbars between Maithon Panchet reservoirs and Paikpara village. All of these sandbars have been considered in reviewing generalized land use characteristics and the resultant landscape through human intervention.

6.3 Land Use Planning in the Riverbed: Maithon Panchet Reservoirs to Barsul Chanchai

The three sectors of the Damodar between the Panchet and Maithon reservoir and the Falta outfall mentioned previously will be discussed in turn in the following sections. Each riverine bar selected for reviewing land use characteristics will be discussed in detail. For each bar, locational characteristics, hydro-geomorphological phenomena and population characteristics will be considered prior to the discussion on land use. The stretch between the Panchet and Maithon reservoir and Barsul-Chanchai village is subdivided into three sections. The first section is from the Panchet and Maithon reservoir to the Durgapur barrage, the second section is up to the Jujuti sluice and the third section is up to Barsul-Chanchai village where the river takes a sharp turn. This sub-division is based on riverbed and land use characteristics.

6.3.1 Gangtikali

Gangtikali or Gang Tikli means a head ornament in a river. Gang means a river or a stream. Tikli is a head ornament used at the center of the forehead. Gangtikali is an oval shaped rocky island that looks like this head ornament. It is a part of the Raniganj coalfield and is sited just below the confluence of the Damodar with the Barakar. It is located southwest of Asansol, an important urban industrial centre of West Bengal. Gantikali is a part of the Saltora mouza, and is under the police station of Nituria of Purulia district (Fig. 6.1). The nearest railway station is Kulti.

On the Barakar side, Gondwana sandstone, shale and coal seams have been exposed. Some spectacular potholes carved in sandstone are noticeable features of this side which also contains a series of flood-built terraces. Lower terraces are formed of sandy materials with an abundance of quartz and feldspar particles. This rocky island is bounded by a 100 m high contour. The maximum height is 120 m. Although bounded by the Damodar on the south and east and by the Barakar on the West and North, Gangtikali was never flood-prone because of higher elevation. Flood risk has been further reduced due to the Panchet and Maithon dam closures. Due to reduction in monsoon discharge and peak discharge as well, the main settlement and the agricultural fields remain much above the water level for a greater part of the year. Except for the thalweg, both rivers are almost fordable in the dry months.

The total population of Gantikali is approximately 225. There are 50 families. Bihari Kuris, an agricultural caste from the Chhotanagpur, migrated to Gangtikali with the opening of the coal mines. The Gangtikali settlement predates major control

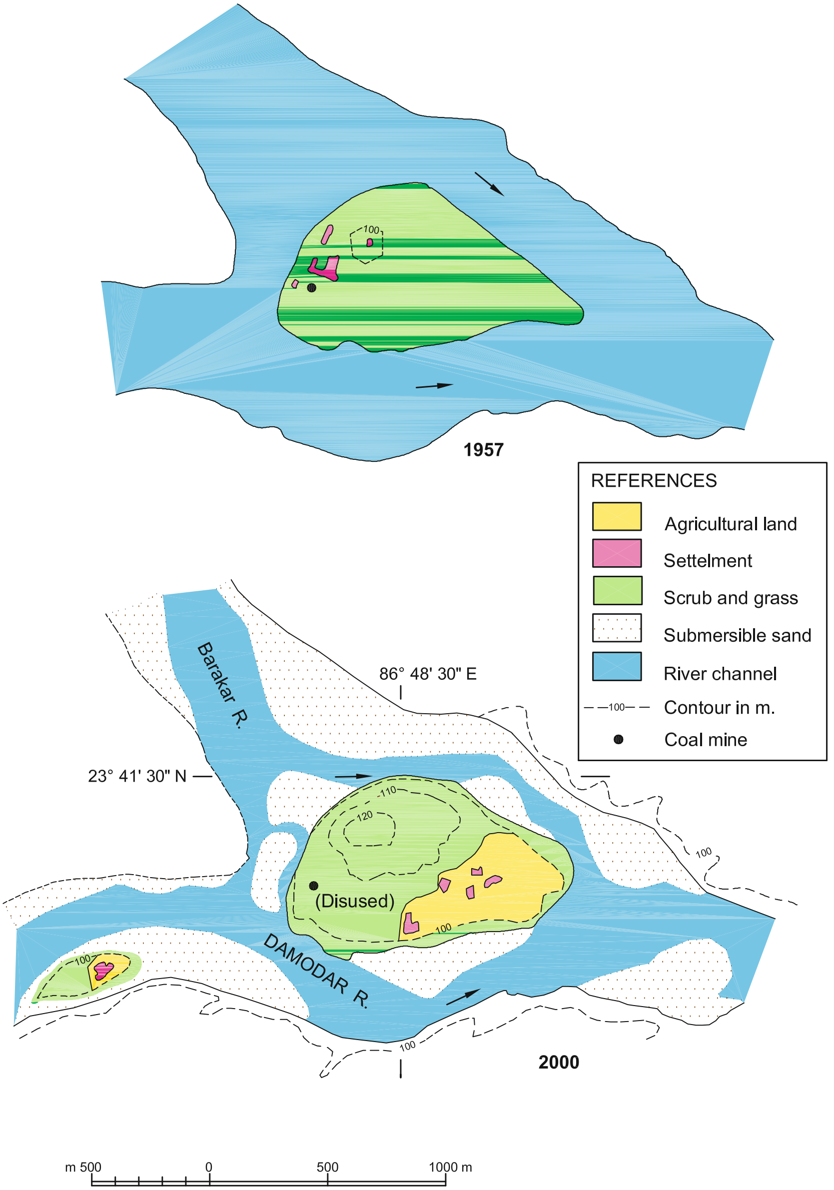

Fig. 6.1 Changing cultural landscape of Gangtikali
Map prepared through active field survey and using several Survey of India (SOI) maps of 73I/10, (1:63,360, 1:50,000). Cadastral map of Saltora is consulted

structures and the contemporary land use and landscape can only be explained if land use characteristics of the early part of the present century are considered. In fact, land use in Gangtikali shows three distinct phases: pre-coal mining, coal mining and post-coal mining. In the pre-coal mining phase Gangtikali was an unpopulated forest-covered island. The forest, therefore, did not have any functional entity and was just one of the components of the natural landscape. With the opening of coal mines in the early part of the twentieth century, organized land utilization started and coal became the main fund resource. Forests were cleared and over burdens were blasted off. Removal of solids from the surface created depressions that were later filled up with water. There were other significant changes in landscape. With the heaves of coal spoils, relief variations were accentuated at a micro level. Noticeable changes also occurred in floristic composition, as forest vegetation degraded to xerophytes scrub vegetation.

The flood of 1958–1959 can be treated as a threshold in the land utilization history of Gangtikali. Mines were flooded and mining activity ceased to be economically viable. At this juncture, agricultural resource potentialities were harnessed in the eastern part of the rocky island. As the islanders are mostly from Bihar, their preferred food crops, wheat and maize, are the main crops grown. There are also guava plantations.

Because of higher elevation from the riverbed, lift irrigation poses a problem. Therefore, release of water from the Panchet/Maithon is perceived as a viable resource and is always welcome. In the coal mining phase, the main settlement was on the northwest of Gangtikali as is evidenced from the SOI map of 1929–1930 and the geological map (1951–1952) of the Raniganj coal field. The present settlement is on the southeastern part of the island. In Gangtikali, changes in cultural landscape are very much prominent (Fig. 6.1). The contemporary landscape consists of two units, the abandoned colliery with coal spoils and depressions, and xerophytic bushes and the agricultural fields with settlements.

6.3.2 Vivekanandapalli Squatters' Colony

The very name of this settlement suggests that it is a colony of displaced people. The settlement is named after Vivekananda, a notable Bengali religious figure. Popularly known as Telenda Mana, this settlement is sited on a marginal bar and situated upstream of the Durgapur barrage. The alluvial bar is a part of the Telenda and Mejia mouzas under the police station of Mejia, Bankura district. The closest large settlements are the Mejia thermal power station and Andal, the biggest railway yard in India.

The alluvial bar is bounded to the north by the Damodar and to the south by the Gaighata Jhor. Despite being situated between a reservoir and a barrage, Telenda Mana is not usually flooded when water is released from the reservoirs since the main flow of the Damodar is away from the settled bar. On rare occasions, there may be backrush from the barrage and the bar gets flooded by the Gaighata and Damodar as well. Sands are the dominant surface materials.

The Telenda Mejia Mana settlement is a refugee settlement. In the portion of the sandbar under the Telenda mouza there are 28 families and 32 households with a total population of about 225. In the portion of the sand bar under the Mejia mouza there are only about 9 families with a total population of 50. Prior to human habitation, almost the entire sandbar was covered with jungles and wild grasses. Scrubs and grasses are still seen in some areas, however, most of the grasses have been cleared since Bangladeshi refugees started colonizing the bar in 1956.

Wet rice and jute were introduced to Telenda Mejia Mana by Bangladeshi refugees as major cereal and cash crops. Both crops are part and parcel of agriculture in the Bengal delta but jute was not an important cash crop in this part of Bankura. With the application of fertilizers, nutrient status of the soil has improved. In addition to rice and jute, wheat and potato are grown as spring crops. Fast-growing vegetables and fruits such as cucumber and watermelons are grown with the lowering of river water level on the margin of Telenda Mana. These *zaid*, or additional crops, are sown in February and March and harvested in summer.

Though the marginal bar is not very inundation-prone, agricultural plots are aligned transverse to the Damodar and the Gaighata jhor so as to avoid disaster from floods in unusual years. The riverbed of the Gaighata jhor is used for additional crops (Fig. 6.2). As the main flow of the Damodar is away from the agricultural fields, the Gaighata jhor is perceived and treated as the main source of irrigation. At present almost all households have tube well facilities.

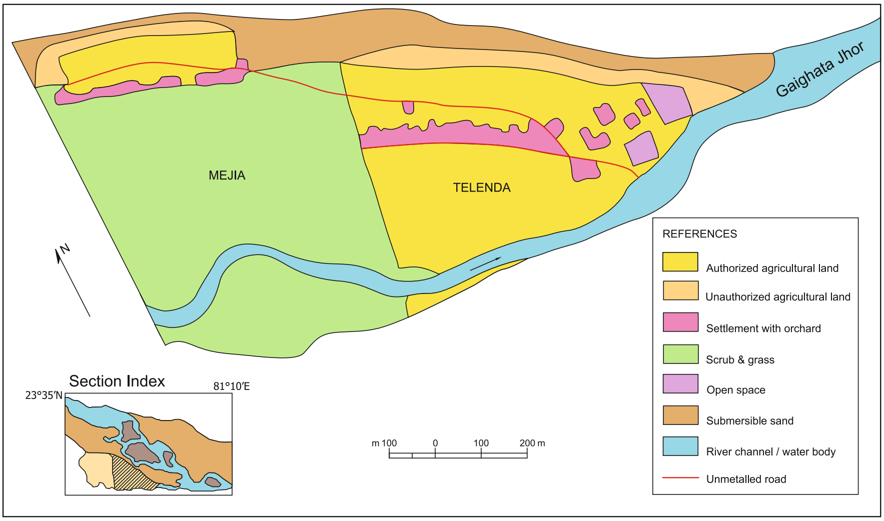

Fig. 6.2 Vivekananda Palli Squatters' colony: land use characteristics
Map prepared through active field survey and using several layout plans (Cadastral maps of Telenda and Mejia) originally prepared between 1994 and 1995 and modified between 2007 and 2008 with active support from Refugee Relief and Rehabilitation Department (RR&RD), Bankura, Govt. of West Bengal

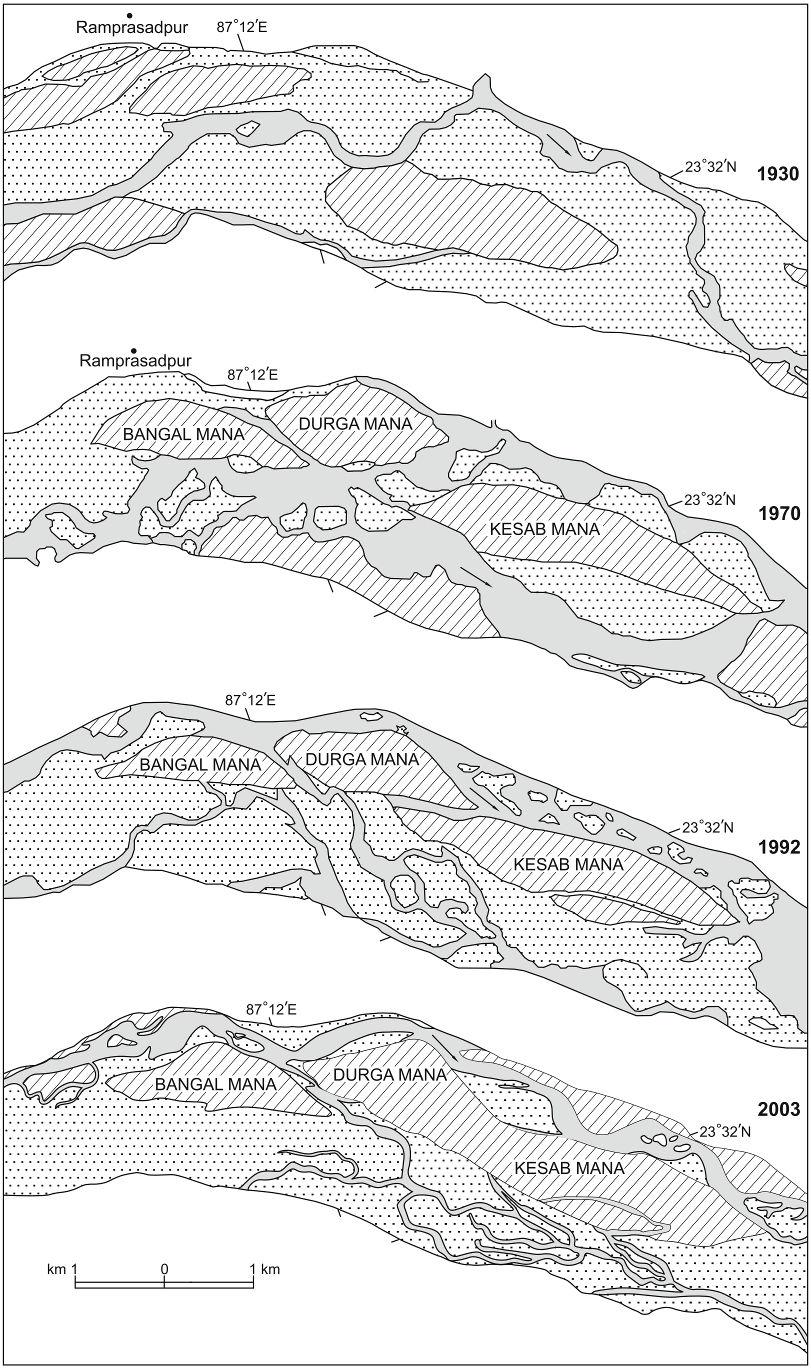

Fig. 6.3 (continued)

The settlements are mostly on the highest part of the bar although flood risk is very low in Telenda Mana in general. A new settlement, Mejia Mana, known as new Vivekananda Colony, has developed towards the Panchet. This is away from the Gaighata jhor and sited towards the northern bank of the Damodar. Both the settlements are linear in pattern.

6.3.3 Damodar Char Mohana

The Damodar Char Mohana colony consists of Bangal Mana, Keshab Mana and Durga Mana. All types of bars are referred to as *Char* in Bengali. In Bangladesh Chars are locally known as *Mana* derived from *Mohana* which usually denotes a confluence of river and sea. Erstwhile East Bengalis and the present Bangladeshis are often referred to as *Bangal* in West Bengal. Since Keshab and Durga are names of a Hindu god and a goddess, the very names of the settled sandbars indicate that the settlers are Bangladeshi Hindus. Damodar Char Mohana colony is sited upstream of the Durgapur barrage in the police station of Mejia of the district of Bankura. These sandbars consist of portions of five mouzas: Balarampur, Damodar Mohana, Debagram, Purbator and Dighal Gram.

These sandbars are elongated. The SOI map of 1929–1930 shows this alluvial bar as several small bars in a braided channel covered with grasses but the SOI map of 1969–1970, IRS Geo-coded imagery of 1992 and 2003 LISS-3 scenes of IRS-1D satellite show the bar as a more or less continuous one. Bar materials vary from fine sands to coarse sands. Although fragmented bars have merged with each other, some of the decaying channels can still be seen in the Damodar Char Mohana colony. The depth of the water table is 12 m. Since the area is situated between the reservoirs and a barrage, the risk of inundation is very high. Monsoon inundation risk has decreased after the construction of the Maithon and Panchet reservoirs. Apart from inundation, proximity to the barrage makes the settlement vulnerable to backrush of water from the barrage. Also, extraction of sands by coal boats on the left bank has deepened the channel and the Geo-coded map of 1992 show severe bank erosion and size reduction of these bars (Fig. 6.3). These sandbars are merging together as is evident from the 2003 LISS-3 scenes of IRS-1D satellite image.

◄

Fig. 6.3 Changing river bed morphology: Damodar Char Mohana
The maps drawn from the Survey of India (SOI) maps (73 M/2, 1: 63,360, 1: 50,000), Geocoded Imagery of 1992 (1:50,000) and 2003 LISS-3 scenes of IRS-ID satellite are shown. The maps show changes in the river between 1930 and 2003. In 1930 the river occupied a portion of the area divided by unvegetated bars. In 1970 the stream flow had been divided by vegetated bars. People have occupied these sandbars. In 1992 the right bank flow was diminished and the river looks narrower than in former times. In 2003, the sand bars were getting enlarged. Planform evolution has been shown using a sequence of pictures rather than by superposition because the braided and anastomizing patterns would create a very confusing image

Bangal Mana and Kesab Mana are both refugee-dominated sandbars, whereas Durga Mana is a Bihari dominated village. There are about 180 families with a total of more than 1,500 people. Land use in these bars is finely adjusted with inundation risk. If the duration of floods is short, the current is mild, and silt deposition is rich, the prospect of a bumper harvest is very high. On the other hand, if the flood retreat phase aggravates bank erosion and scouring of the riverbed, utilization of the riverbed is hampered. The floods of 1978, 1995, 2000, and 2007 have done extensive damage to the Damodar Char Mohana colony. Two crops are usually grown every year on these bars. *Kharif* crops are sown after the first shower of monsoon and are harvested after the last spell of monsoon. *Rabi* crops are winter crops that are sown in the autumn and harvested in the spring. If there is flooding on the bar due to excess release of water from the Panchet, sowing of Rabi crops may be delayed. An additional crop, or *zaid*, is also grown on the periphery of the alluvial bar when water level falls and fresh sand deposits are exposed. Kharif crops include rice, pulses, groundnuts, fruits, and vegetables. Rabi crops grown in the bar are rice, wheat, oil seeds, pulses and vegetables.

Wheat is the preferred crop of Bihari families in Damodar Char Mohana. The Bengalis also cultivate wheat as there is a ready market for this crop. Potato cultivation requires continuous vigil, repeated watering at least five to six times a day and several weeding operations. Potato is grown in sandy loam but in the vicinity of settlements. Chilli is a major cash crop in the district of 24-Parganas (South), and the Bangladeshi refugees have introduced chilli as an important cash crop to this bar. The first crops grown on this bar were cucumber, watermelon, bitter gourd and long melon that were planted on fresh sands which are believed to be of low nutrient status. These are zaid, or additional crops. Perennial grasses are allowed to grow on banks that are erosion-prone due to high inundation. These grasslands are carefully maintained.

Pronounced relief variations cannot be expected in an alluvial bar. But relief variations at the micro level can be identified from observations of the cultural landscape. Settlements and perennial tree crops indicate inundation-free higher elevation. Settlements in the Damodar Char Mohana are sited on the highest elevation, and individual houses are constructed on higher plinths above the usual inundation level. The settlers were thus not much affected in the flood years of 1958, 1959, and 1971. The floods of 1978, 1995, 2000, and 2007, however, caused some damage to the houses on the bar. The settlements are dotted with perennial crops such as mango and jackfruit. The zone below the highest elevations is devoted to the cultivation of cereals and important cash crops. Inundation-prone low-lying areas are left for inferior types of vegetables and fruit crops mentioned above. The cultural landscape of the Damodar Char Mohana thus exemplifies the concept of flood zoning. Spatio-temporal extension of individual zones varies from year to year due to spatio-temporal variations in release of water from the Panchet and Maithon reservoir. Riverbed sands are extracted by coal boats for sand stowing in the collieries of the Ranigunj. As a consequence, the inactive riverbed on the left side has been deepened and this has posed a threat to the stability of the bar.

Colonization in the Damodar Char Mohana started rather late because of its high inundation risk. From 1956 onwards the Bangladeshi refugees started occupying this riverine bar. Now they have been granted land deeds, although the DVC authority does not like the idea of permanent settlements in such a vulnerable riverbed. Dried up channels are used as village roads and are important components of land use. There was a school but the school building was demolished during the 1995 floods and had to be reconstructed.

6.3.4 Ramakrishna Palli, Pallishri and Sitarampur Mana

The Ramakrishna Palli, Pallishri Sqatters' colony, and Sitarampur Mana are sited on a marginal sandbar and the first two are separated by a narrow dried-up channel. These sandbars are situated below the Durgapur barrage within the Barjora police station of the Bankura district and comprise parts of Paharpur, Krishnanagore, and Bamandihi mouzas. The settlements have been named after Ramkrishna, a Hindu religious figure, and Sita and Ram, epic characters of the Ramayana. Palli means a village and Shri means beauty. Pallishri used to be a squatters' colony but the residents have now been granted land deeds.

Rivers are natural boundaries and are often taken as demarcating lines between countries, states and districts. Political boundaries change over time but usually remain static within a short time horizon. Although bedrock-controlled rivers are usually fixed in their position within graded time, alluvial channels in their low gradient sectors keep on changing their positions within the same graded time frame. Braided and meandering channels, in particular, often shift as a consequence of channel adjustment with discharge, load and gradient, often shifting far away from the political boundary. The political boundaries thus help in identifying the shifting nature of a river.

In this part of the study area, the Damodar used to define the administrative boundary between the districts of Barddhaman and Bankura. The cadastral map of 1957 shows this sandbar as existing within a channel riverine bar. But in 1996 the bar appeared to be a part of the mainland as the main Damodar has shifted far south of its previous position.

The Cadastral map of 1957 (Fig. 6.4) shows:

i. A wide Damodar main channel (D1)
ii. A narrow channel between two bars (D3)
iii. A very narrow meandering channel towards the district boundary (D2)

By 2003–2007, however, the map (Fig. 6.5) shows

i. The main Damodar (D1) has become very narrow on the right side, as a big sandbar, though transient in nature, has emerged
ii. The previous channel separating two bars has become a feeble channel (D3)
iii. A narrow channel (D2) towards the district boundary can still be observed

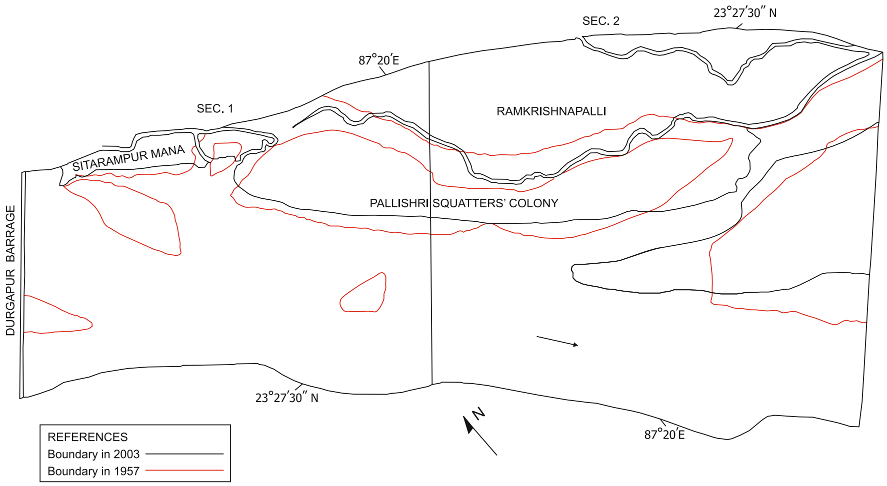

Fig. 6.4 Changing boundary of Sitarampur Mana, Ramkrishna palli and Pallishri squatters' colony Maps prepared from cadastral maps (Paharpur, Krishnanagore, and Bamandihi), 2003 LISS-3 scenes of an IRS-ID satellite from Indian National Remote Sensing Agency (NRSA), Hyderabad and layout plans prepared between 1994 and 1995 and modified in 2007 and 2008

iv. There is an ill-defined channel (D4) separating the transient sandbar and the settled sandbar of the Ramkrishnapalli and Pallishri colonies
v. There is another feeble channel (D5) north of the Sitarampur Mana.

Due to controlled release of water from the reservoirs and the presence of a sandbar just below the settled bar, inundation risk is usually low in this area. The ill-defined channel (D4) gets activated when there is excess release of water from the reservoirs. The 1978 floods inundated the entire bar and caused damage by riverbed scouring but did not totally destroy the bar. The flood of 1995 also did damage but only for a few hours since the barrage started releasing water at midnight on 29th September 1995 and the release of water continued for 10 h. The flood of 2007 also did damage when the barrage started releasing water on 25 September.

The Ramakrishna Palli, Pallishri, and Sitarampur Mana bar is settled by Bangladeshi Hindu refugees. Changes in generalized land use characteristics and landscape are shown (Fig. 6.5). The bar material varies from fresh sand to clay, and these clay deposits are to be found on the beds of D2, D3, and D4. In the dried-up portion of D3 the river bed is used for double cropping (Figs. 6.6 and 6.7). Clay deposits of the dried up channel are good for rice culture (Plate 6.2). This indicates that the people can perceive deposition of clay materials in decaying channels and the higher field capacity of clay soil. Residents can assess the resource potentialities of the sandbars.

Multiple cropping is a common practice in this alluvial bar. Additional crops are grown on the bed of D4 and in areas adjacent to it. These are unauthorized agricultural fields. There is a small sandbar between Bara Mana and these bars, but

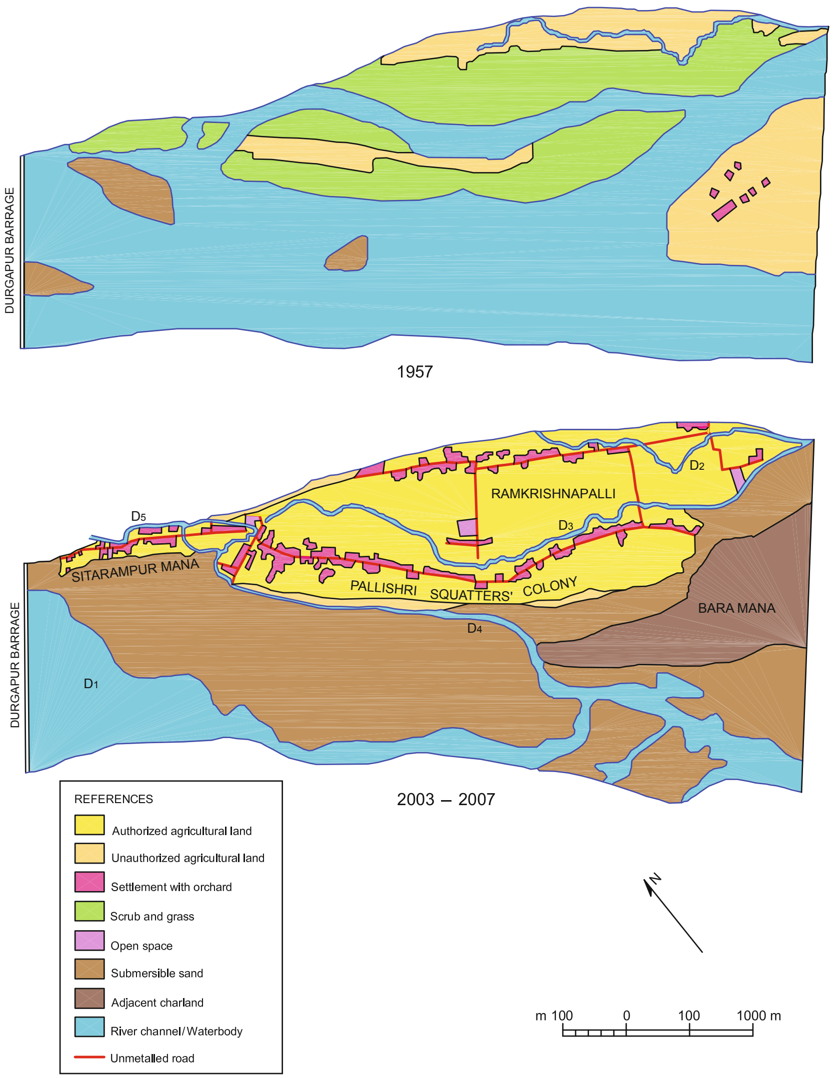

Fig. 6.5 Sitarampur Mana, Ramkrishna palli and Pallishri Squatters' colony: changes in generalized land use characteristics and landscape
Map prepared from cadastral maps (Paharpur, Krishnanagore, and Bamandih), Survey of India (SOI) maps of 73 M/7 N.W (1:25,000), 73 M/7 (1:50,000), 2003 LISS-3 scenes of IRS-ID and layout plans prepared between 1995 and 1997 and modified between 2007 and 2008

this small bar has merged with Bara Mana. This bar is also extensively cultivated but there are no settlements on it as residents perceive this sandbar as vulnerable to inundation when channel D4 becomes reactivated (Fig. 6.5). Almost all types of vegetables, oilseeds, and cereals are grown here. Comparatively infertile lands are used for cultivation of a coarse variety of jute (Mesta). Oilseeds grown in this sandbar are

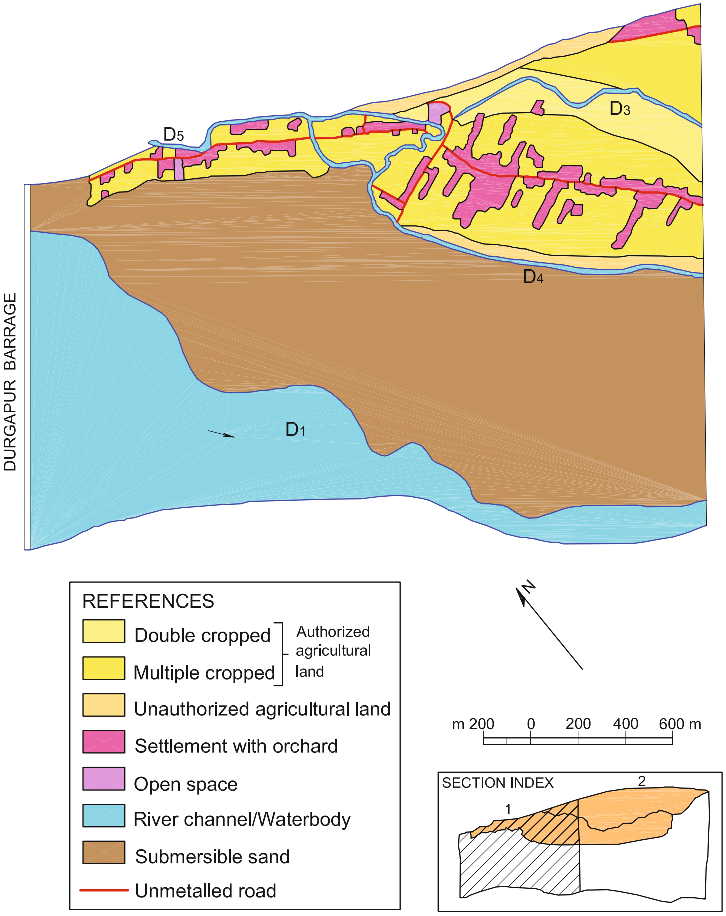

Fig. 6.6 Sitarampur Mana, Ramkrishna palli and Pallishri Squatters colony (Section-1): land use characteristics
Map prepared through active field survey

mustard and sesame. Cereals like rice and wheat are also grown here. Many types of vegetables such as pointed gourd (*T. dioica*), potato, bringal (*Solanum melongena*), and Chilli (*Capsicum frutescens*) as well as winter vegetables such as pea (*pisum sativum*), cauliflower, and cabbage are grown here. The Figs. 6.5, 6.6 and 6.7 show hydro-geomorphological characteristics and land use features that include the channels of D1–D5. The emergence of new sandbars and areas of double and multiple cropping are visible. The main Pallishri settlement is located away from the channel D1 at a higher elevation. This part of Pallishri, incidentally, has been the most stable part of the sandbar since 1957. Ramkrishnapalli is located close to the district boundary. The Sitarampur Mana is an extension of the Pallishri colony. Village roads are almost parallel to each other. In fact, village roads follow the boundary line between agricultural plots, particularly towards the southwestern part of Pallishri. These series of small village roads have not been shown (Fig. 6.6).

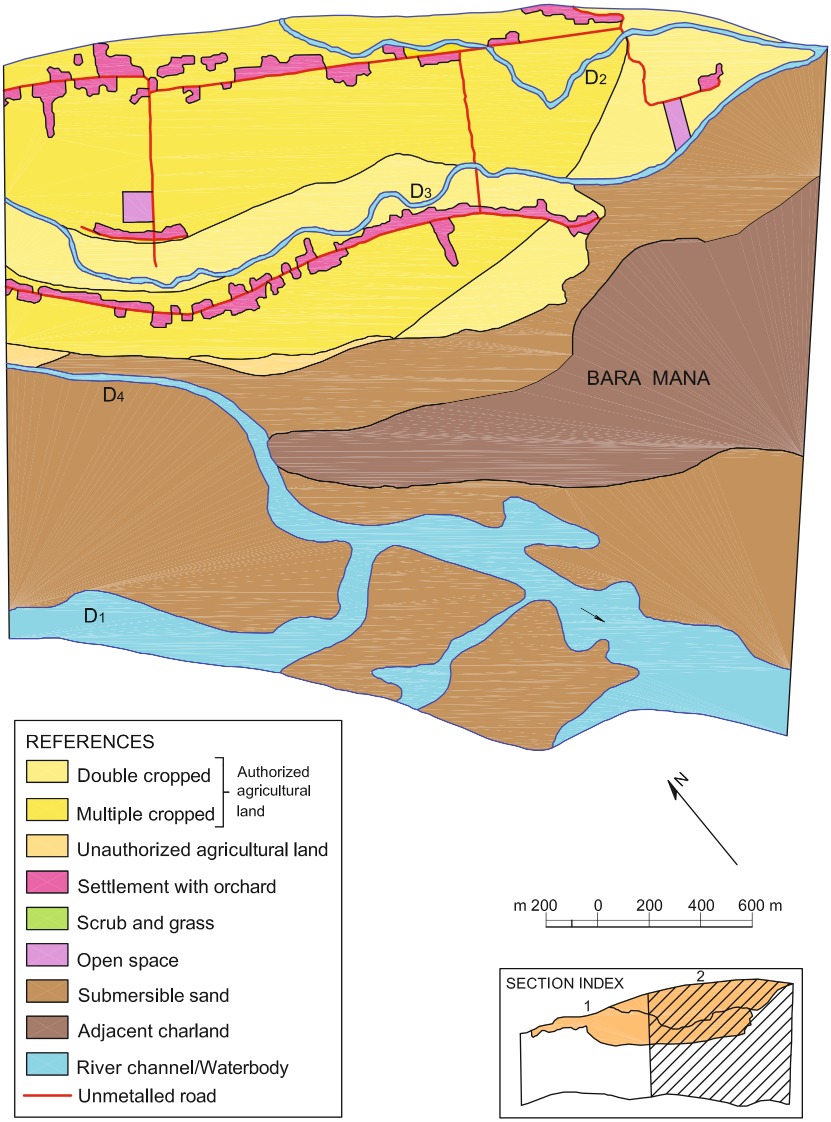

Fig. 6.7 Sitarampur Mana, Ramkrishna palli and Pallishri Squatters colony (Section-2): land use characteristics
Map prepared through active field survey

6.3.5 Bara Mana

Bara Mana, the largest alluvial sand bar in the culturally defined Lower Damodar, is sited below the Durgapur barrage. The Chhota Mana, located in the extreme western side under Bamandihi mouza, and the Saha Mana, located within Pakhanna–Bhairabpur mouza, are included within this bar. Bara Mana is part of eleven mouza maps or villages. They are Bamandihi, Purakonda, Tajpur, Pakhanna Bhairabpur, Pakhanna, Radhakantapur and Gopalpur under Barjora Police Station and Palashdanga, Jaynagar, Alampur and Dihipara under Sonamukhi police station of the Bankura district. The total area of Bara Mana is approximately 11 km^2. Durgapur and Panagarh are the nearest towns and railway stations towards the Barddhaman side. They are approachable by ferry service from Pakhanna in the district of Bankura. Bara Mana is an elongated mid-channel bar with a maximum length and width of 11 and 1.5 km respectively. The highest elevation is 62 m (above mean sea level now in Karachi, Pakistan).

The evolutionary history of Bara Mana has been traced using mouza maps of three series: Cadastral survey (CS) maps, surveyed between 1917 and 1921, Revision Survey (RS) maps surveyed between 1954 and 1957, and Layout plans surveyed between 1994 and 1997 (unpublished), SOI maps 73 M/7 surveyed between 1969 and 1985 (1:50,000, 1:25,000), and the 2003 LISS-3 scenes of the IRS-1D satellite. For detailed analysis, the Bara Mana has been divided into six sections taking mouza boundaries as lines of demarcation. Mouza boundaries follow straight lines at the riverbed and small mouzas have been treated together or included with larger ones. In 1921 there were two sand bars. By 1957, the bars had merged together to form an elongated bar (Fig. 6.8). In later years this alluvial bar has been truncated

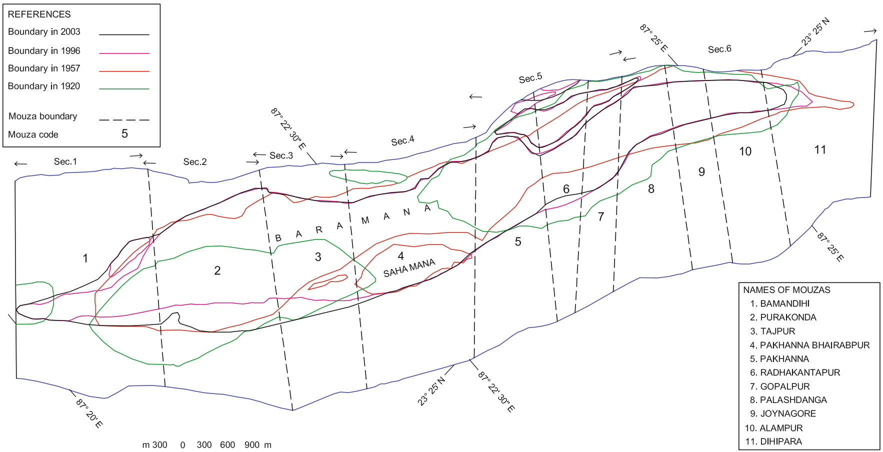

Fig. 6.8 Changing boundary of Bara Mana
Maps prepared from cadastral maps, SOI maps, and 2003 LISS-3 scenes of IRS-ID satellite.

Cadastral Survey (CS) maps (Bamandihi, Purakonda, Tajpur, Pakhanna Bhairabpur, Pakhanna, Radhakantapur, Gopalpur under Barjora Police Station and Palashdanga, Jaynagar, Alampur and Dihipara under Sonamukhi police station of the Bankura district), 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.

Survey of India (SOI) maps of 73 M/7 N.E., 73 M/7 N.W., 73 M/7S.E. (1:25,000), 73 M/7 (1:63,360, 1:50,000), IRS Geo-coded imagery 73 M/7, satellite image of 1994 IRS IB LISS-2 FCC classified image 1:100,000 have been consulted and elongated at the western end. At some places in the eastern and western sectors Bara Mana is very narrow. Since 1957, the Saha Mana situated below section 4 appears to be a stable bar. It is separated from the main alluvial bar by a feeble channel which is almost choked with sand deposits, and is now part of the Bara Mana. The main thalweg (D1) has always been on the right side. Because of several transient bars not shown in the figures, the thalweg appears to be sinuous and is deep enough for ferry service between May and January. A less sinuous channel (D2) north of the Bara Mana is fordable throughout the year. In the dry season this channel almost disappears or becomes disconnected pools. As a result, Bara Mana becomes a part of the mainland (Plate 6.3a and Plate 6.3b) connected through this motorable channel. Despite enlargement since 1920, Bara Mana still suffers from bank erosion in many places (Plate 6.4). Contemporary hydro-geomorphological conditions on the left bank strongly indicate the merging of the Bara Mana with the mainland in the near future (Plates 6.1, 6.3a, and 6.3b).

Over the decades, grass-covered land of Bara Mana has been transformed into agricultural fields (Figs. 6.9, 6.10, 6.11 and 6.12). On the cadastral maps of 1957 some unauthorized agricultural fields are found and permanent settlements have arisen after 1957 and 1959 after completion of the Durgapur barrage, and the Maithon and Panchet reservoirs.

Bara Mana is dominated by Bangladeshi refugees. After 1978 a few locals migrated from the districts of Medinipur and Hooghly and have purchased land from refugees. The total population of Bara Mana is approximately 7,000.

6.3.5.1 Land Use Characteristics and Flood Zoning in the Riverbed

To examine changes on the bar and the land use characteristics, Bara Mana has been divided into six sections.

Section-1 comprising Bamandihi mouza are shown in Fig. 6.13 from which the following observations are made.

i. Grasses are allowed to grow on the erosion-prone bank
ii. Jute is cultivated in the next zone
iii. Double cropping is a common feature on the extreme west of Bamandihi
iv. Additional crops are grown in the unauthorized plots towards the north
v. Multiple cropping is practiced on higher land above the inundation level
vi. Linear settlements are to be found on higher ground in the flood-free area
vii. 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.

Section-2 (Fig. 6.14) comprising Purakonda mouza shows more-or-less similar features. Some added findings are:

i. The river bed of the D2 and unauthorized land in the north are intensively cultivated (Plates 6.3b, 6.5)
ii. Cocoon rearing mulberry cultivation is observed on the highest part of the bar (Plate 6.6)

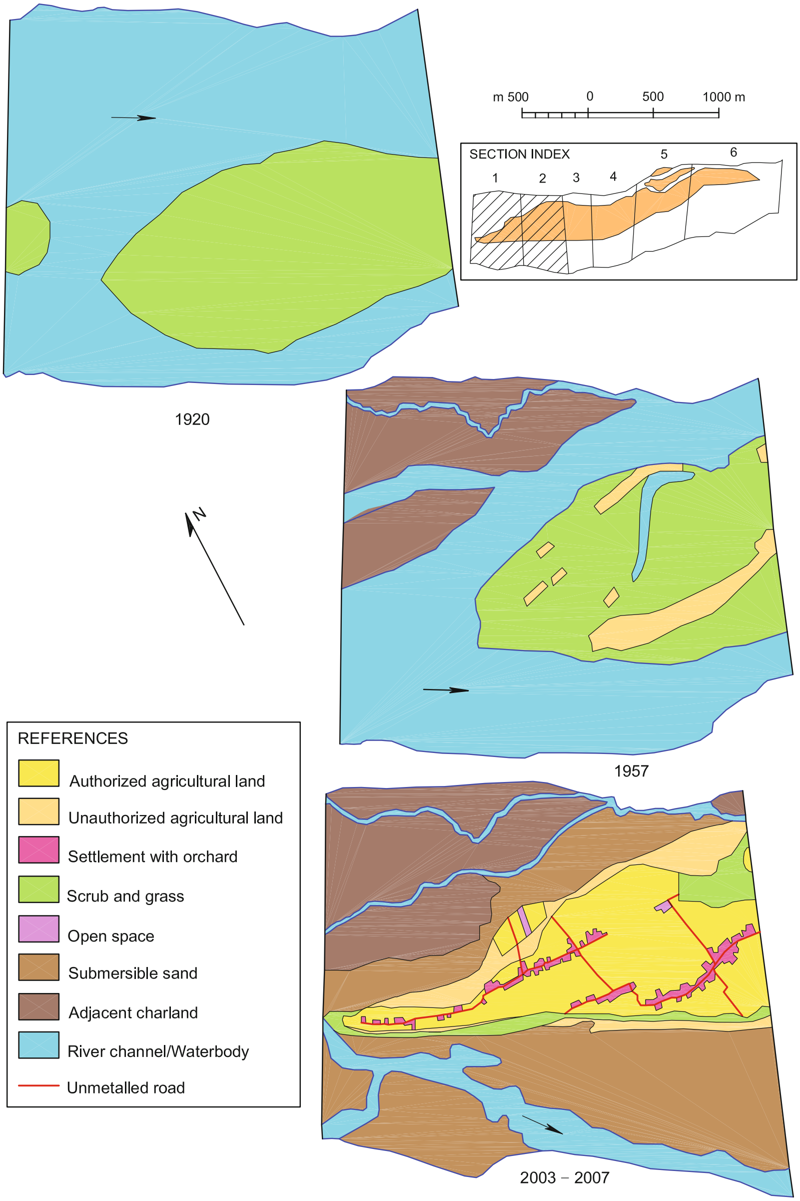

Fig. 6.9 Bara Mana (Sections-1 and 2): Changes in generalized land use characteristics and landscape – Bamandihi and Purakonda Mouza Maps
Map prepared through active field survey.

Bamandihi and Purakonda mouza, SOI 73M/7 (1:63,360, 1: 50,000 & 1: 25,000), and satellite image (2003) has been used to prepare this section of Bara Mana

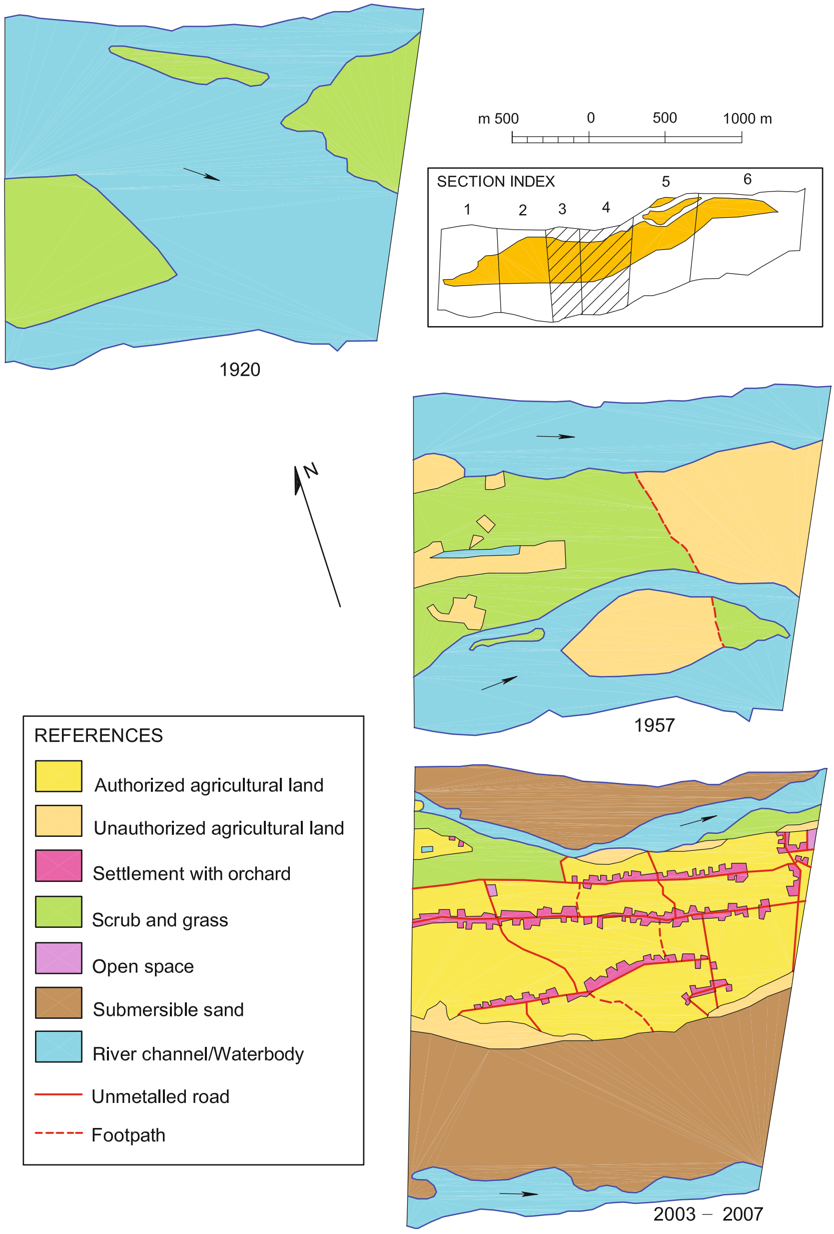

Fig. 6.10 Bara Mana (Sections-3 and 4): Changes in generalized land use characteristics and landscape – Tajpur and Pakhanna Bhairabpur Mouza Maps
Map prepared through active field survey.

Tajpur and Pakhanna Bhairabpur mouza maps, SOI 73M/7 (1:63,360, 1: 50,000 & 1: 25,000), and satellite image (2003) has been used to prepare this section of Bara Mana

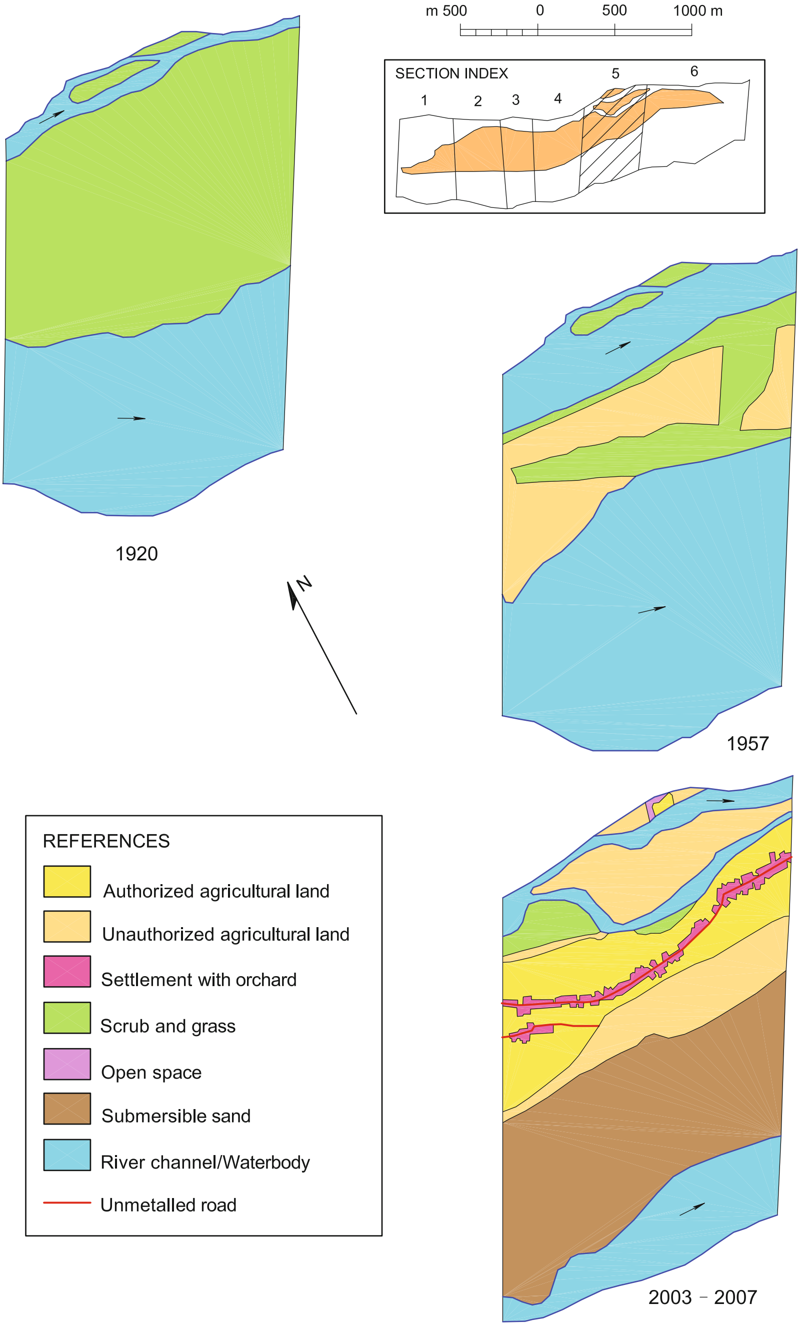

Fig. 6.11 Bara Mana (Section-5): Changes in generalized land use characteristics and landscape – Pakhanna Radhakantapur and Gopalpur Mouza Maps
Map prepared through active field survey.

Pakhanna, Radhakantapur, and Gopapur mouza maps, SOI 73M/7 (1:63,360, 1: 50,000 & 1:25,000), and satellite image (2003) has been used to prepare this section of Bara Mana

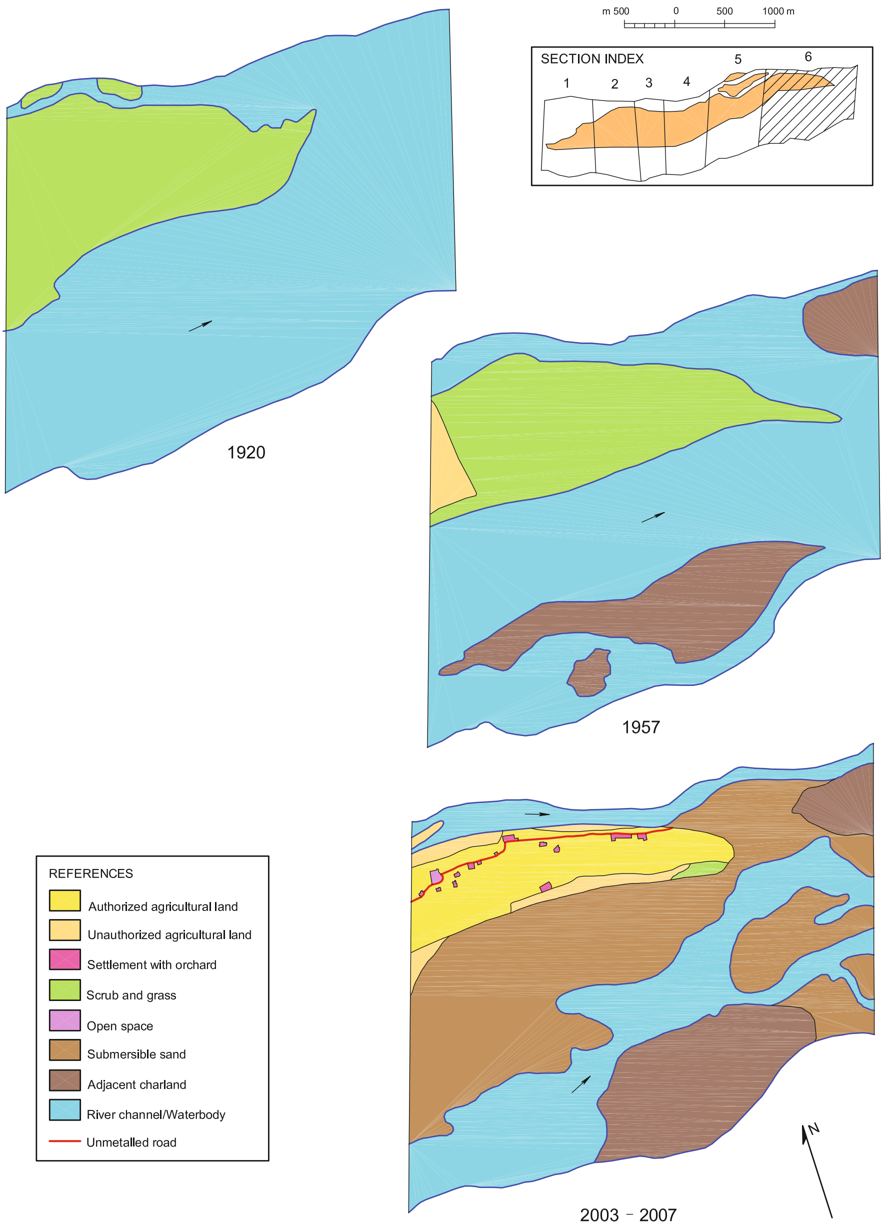

Fig. 6.12 Bara Mana (Section-6): Changes in generalized land use characteristics and landscape – Palasdanga, Joynagore, Alampur and Dihipara Mouza Maps
Map prepared through active field survey.
Palasdanga, Joynagore, Alampur, and Dihipur mouza maps, SOI 73M/7 (1: 50,000 & 1: 25,000), and satellite image (2003) has been used to prepare this section of Bara Mana

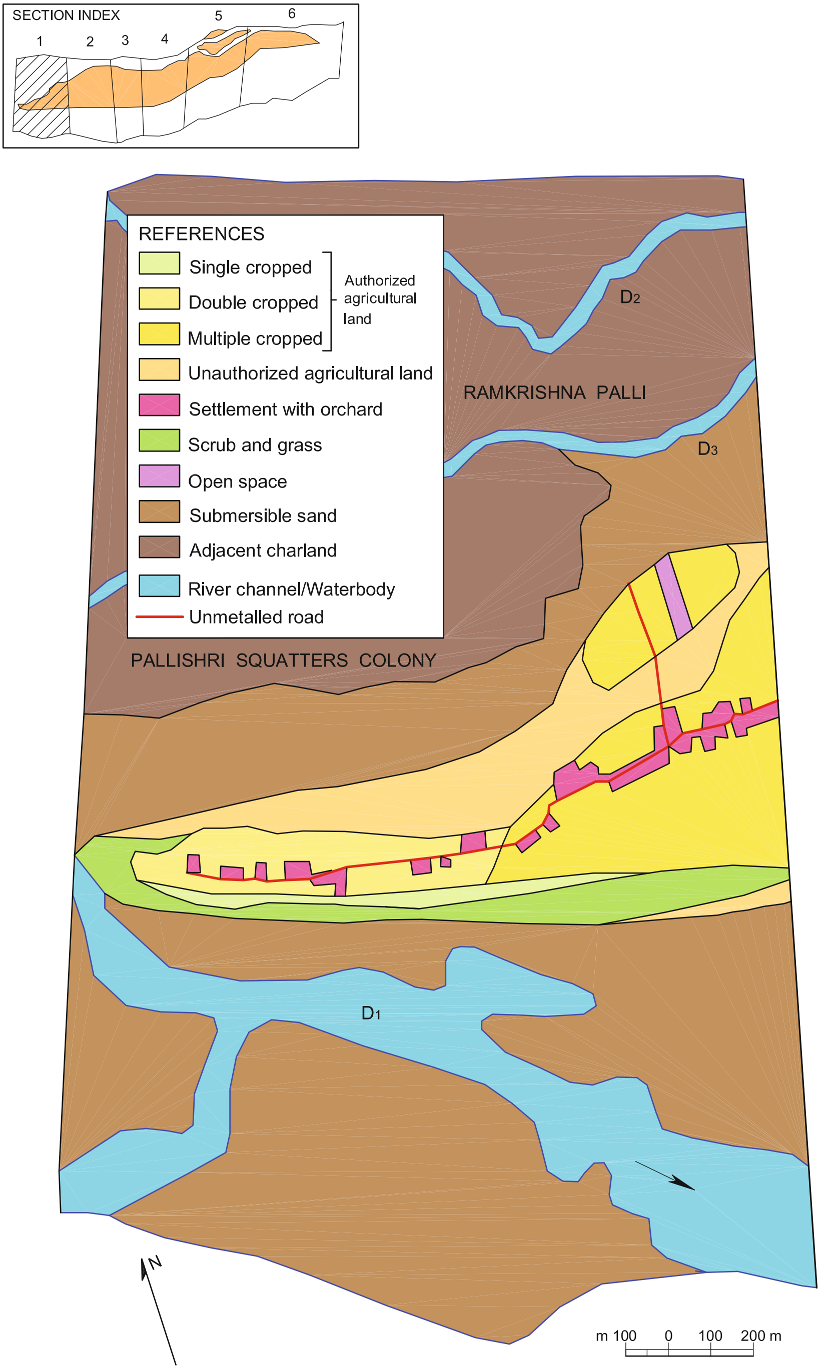

Fig. 6.13 Bara Mana (Section-1) land use characteristics: Bamandihi Mouza
Map prepared through active field survey.

Bamandihi mouza, SOI 73M/7 (1:63,360, 1: 50,000 & 1: 25,000), satellite image (2003) has also been consulted

iii. Clay deposits in the dried up channel D6 is used for rice culture
iv. Scrub and grass covered area is found to the northeast of this section.

Section-3 (Fig. 6.15) comprising Tajpur mouza shows:

i. Cocoon-rearing mulberry cultivation is found on the highest part of the bar
ii. Settlements are strikingly linear along the main road and located on higher ground (Plate 6.7a, 6.7b, 6.7c)
iii. Multiple crops are found on the higher parts of the bar with irrigation facilities (Plate 6.8a, 6.8b, 6.8c, 6.8d).

Section-4 (Figs. 6.10 and 6.16) comprising Pakhanna Bairabpur mouza shows:

i. Saha Mana, a small sand bar situated below, has completely merged with the Bara Mana due to continuous cultivation of the narrow channel between the two
ii. Linearity in settlement pattern is also observed
iii. Floriculture is found on the higher parts of the bar (Plate 6.9a, 6.9b)
iv. A cooperative society, club, play ground, and open space with school are found in this section. The open space with school is utilized as a shelter during high floods (Fig. 6.16).

Section-5 (Fig. 6.17) comprising Pakhanna Radhakantapur and Gopalpur mouzas shows:

i. The southern part is extremely erosion-prone as is observed from Fig. 6.17
ii. There are plots showing temples, ponds, school, and recreational ground
iii. The unauthorized agricultural fields in the northern and southern part are intensively cultivated for additional crops
iv. A small sandbar on the left bank has authorized agricultural fields but is devoid of any settlements.

Section-6 (Fig. 6.18) comprising Palashdanga, Joynagore, Alampur, Dihipara shows:

i. The Bihari-dominated part is not agriculturally developed
ii. The thalweg is striking in the extreme eastern part, so it is prone to erosion and inundation. This part shows single cropping
iii. The rest of the area exhibits double and multiple cropping
iv. The erosion-prone peripheral area is used as scrub or grassland or for additional crops.

Rice is the main cereal crop and jute has been the most important fibre crop from the very beginning of colonization. In later years, with the increasing stability of the bar, almost all types of vegetables, pulses, and different types of oil seeds are now grown. The most important cash crops, however, are mulberry and potato. Very recently floriculture has been introduced in accordance with the urban culture in nearby Durgapur town (Bhattacharyya 1998).

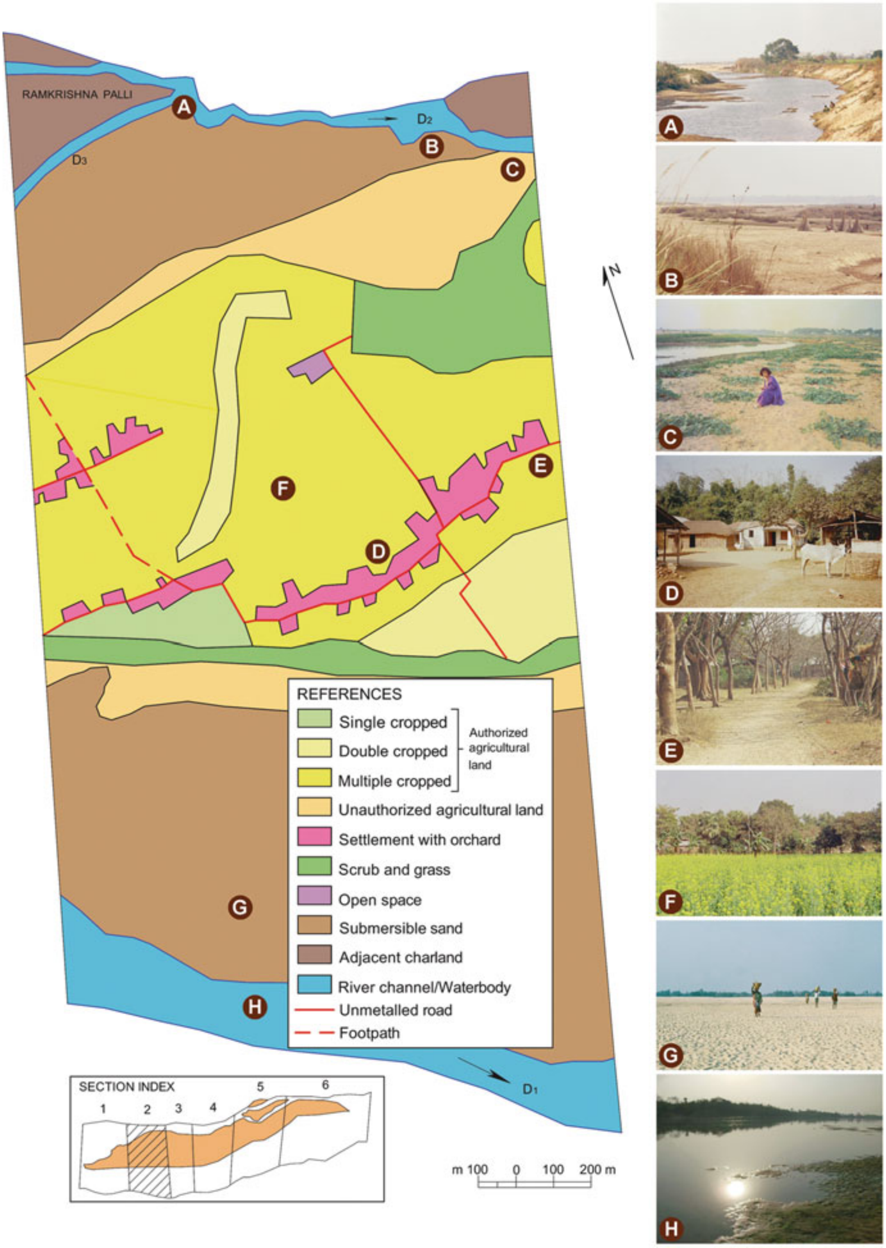

Fig. 6.14 Bara Mana (Section-2) land use characteristics: Purakonda Mouza
Map prepared through active field survey between 1994 and 1997 and 2007 and 2008. Purakonda mouza, SOI 73M/7 (1:63,360, 1: 50,000 & 1: 25,000), satellite image (2003) and land cover map prepared from satellite image of 1994 [IRS-IB LISS-2/FCC/classified image (1:100,000)] has also been consulted.

Bara Mana is an epitome of riverbed utilization. Every possible element of available land is put to some use so as to optimize benefits from micro relief variations, edaphic differences and water level fluctuations. Moreover, people's perception of the soil-binding capacity of roots is reflected in carefully maintained grassland in the erosion-prone area. In the decaying channel beds D_2 and D_3, clay deposited from vertical accretion is used for double cropping and the crop selected is clay-loving rice, the main cereal crop in Bara Mana. Jute, the most important fibre crop, is grown in the inundation-prone peripheral area and jute sticks provide building materials. Areas inundated almost every year are devoted to rice culture of High Yielding Variety (HYV) in the non-monsoon period. Residents can estimate how much area will be inundated if release of water below the barrage exceeds 2,832 or 5,664 m^3/s. The Sections, 3 and 4, including Tajpur and Pakhanna-Bhairabpur, are bounded with a 60 m contour with 62 m spot height which is shown on SOI map surveyed in 1970 (Fig. 6.19). These areas of Bara Mana were initially uneven in configuration but have now been leveled for agricultural purposes. An open space with school grounds located in it is believed to be the highest part of the sandbar and is used as a flood shelter during emergencies (Fig. 6.16). Bara Mana residents organize their agricultural space accordingly. Even if their lands get flooded and the usual agricultural calendar is disturbed, quick growing pulses, oil seeds, and vegetables are grown according to Nagen Tarafdar, a well known farmer of Bara Mana. A special type of onion that takes only 1 month to mature is grown in August and harvested in September. Radish is a preferred vegetable for flood-retreat land use. This type of cultivation is locally known as "Poira" cultivation. Fresh sands of low nutrient status in the peripheral zone are used for different types of gourds and melons (Plate 6.5). "Khero," one such variety of gourd previously not consumed by locals, is extensively grown now on fresh sands. These additional crops, requiring minimum care, now have ready markets in adjacent towns and villages. Riverbed depressions formed by scouring during floods are further excavated for household (Plate 6.10). Riverbed (D2) is also used for pisci culture (Fig. 6.16). The extreme flexibility of land utilization in Bara Mana is evidenced by the way in which flood-related loss of resource is compensated for through "Poira" cultivation, double and multiple cropping in certain areas, and also in the way crop diversity is maintained in order to avoid economic loss due to floods (Bhattacharyya 1998, 2009).

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Fig. 6.14 (continued) **Plates**: A. Decaying drying channel (north of Bara Mana) 1997 photo courtesy of Durba Bhattacharyya; B. Jute cultivation on submersible sand at peripheral zone, Baramana 1997 photo courtesy of Durba Bhattacharyya; C. Additional crop cultivation on nutrient poor fresh sand at peripheral zone, Bara Mana 1996 photo courtesy of Durba Bhattacharyya; D. Settlement sited on the highest part of the sand bars Inundation susceptibility reflected in the structure of individual buildings 2000 photo courtesy of M Bharati; E. Linear settlements sited on higher parts of bars along the main road 2000 photo courtesy of M Bharati; F. Multiple cropping at Bara Mana 2008 photo courtesy of Bileswar; G. Lower Damodar below Durgapur Barrage during dry season Laborers going back to Bankura 2008 photo courtesy of Bileswar; H. Damodar thalweg on the right bank 2008 photo courtesy of Bileswar

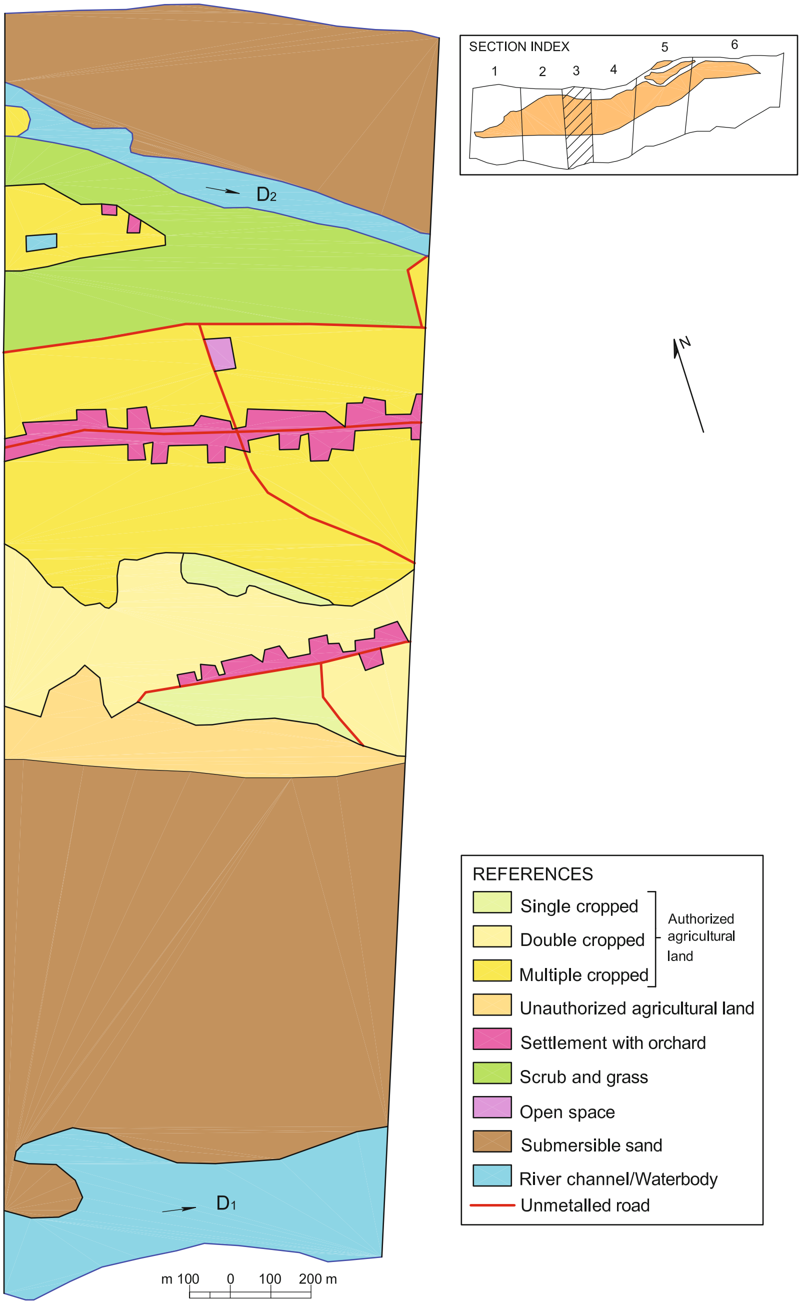

Fig. 6.15 Bara Mana (Section-3) land use characteristics: Tajpur Mouza
Map prepared through active field survey, Tajpur mouza, SOI 73M/7 (1:63,360, 1: 50,000 & 1: 25,000), satellite image (2003) and land cover map prepared from satellite image of 1994 [IRS-IB LISS-2/FCC/classified image (1:100,000)] has been consulted

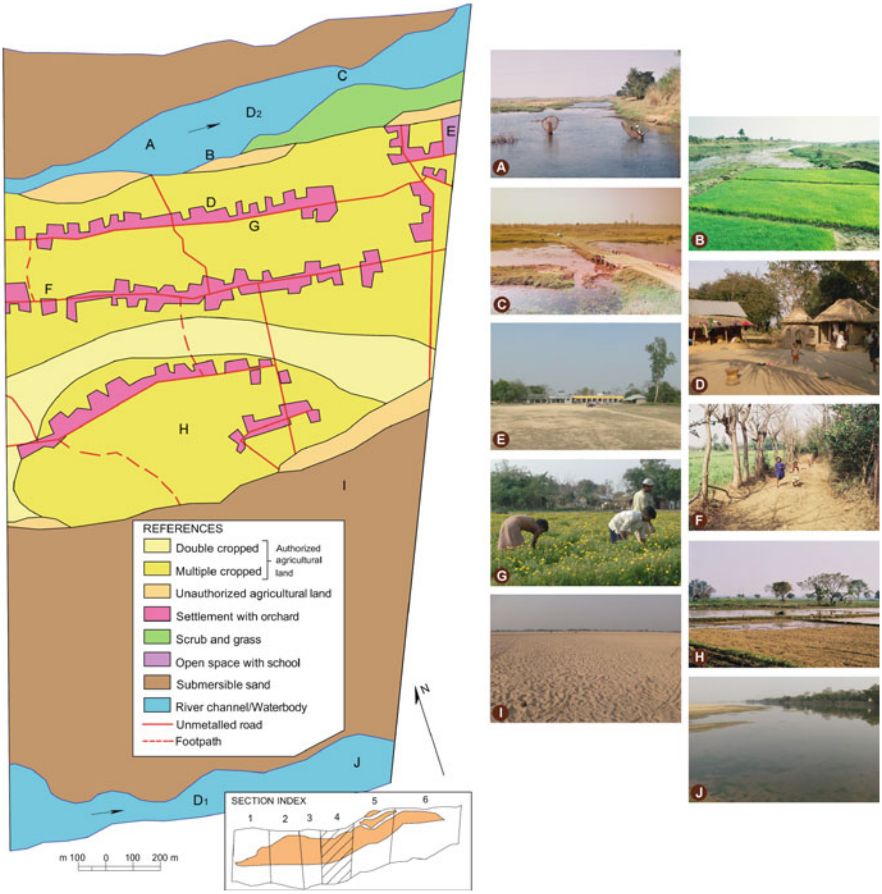

Fig. 6.16 Bara Mana (Section-4) land use characteristics: Pakhanna Bhairabpur Mouza
Map prepared through active field survey, Pakhanna Bhairabpur mouza, satellite image (2003), SOI 73M/7 (1:63,360, 1: 50,000 & 1: 25,000) and land cover map prepared from satellite image of 1994 [IRS-IB LISS-2/FCC/classified image (1:100,000)] has been consulted.
Plates: A. Pisci culture at D2 riverbed at Bara Mana (2000 photo courtesy of M Bharati); B. Additional crop at D2 channel-Bara Mana (2000 photo courtesy of M Bharati); C. Baramana becoming motorable during dry season (2000 photo courtesy of M Bharati); D. Settlement sited on the highest part of the sand bars Inundation susceptibility reflected in the structure of individual buildings (2008 photo courtesy of Bileswar); E. School at highest part of Bara Mana (2008 photo courtesy of Bileswar); F. Linear settlements sited on higher parts of bars along the main road (2000 photo courtesy of M Bharati); G. Floriculture at Bara Mana (2008 photo courtesy of Bileswar); H. Multiple cropping at Bara Mana (2008 photo courtesy of Bileswar); I. Lower Damodar below Durgapur Barrage during dry season (2008 photo courtesy of Bileswar); J. Damodar thalweg on the right bank (2008 photo courtesy of Bileswar)

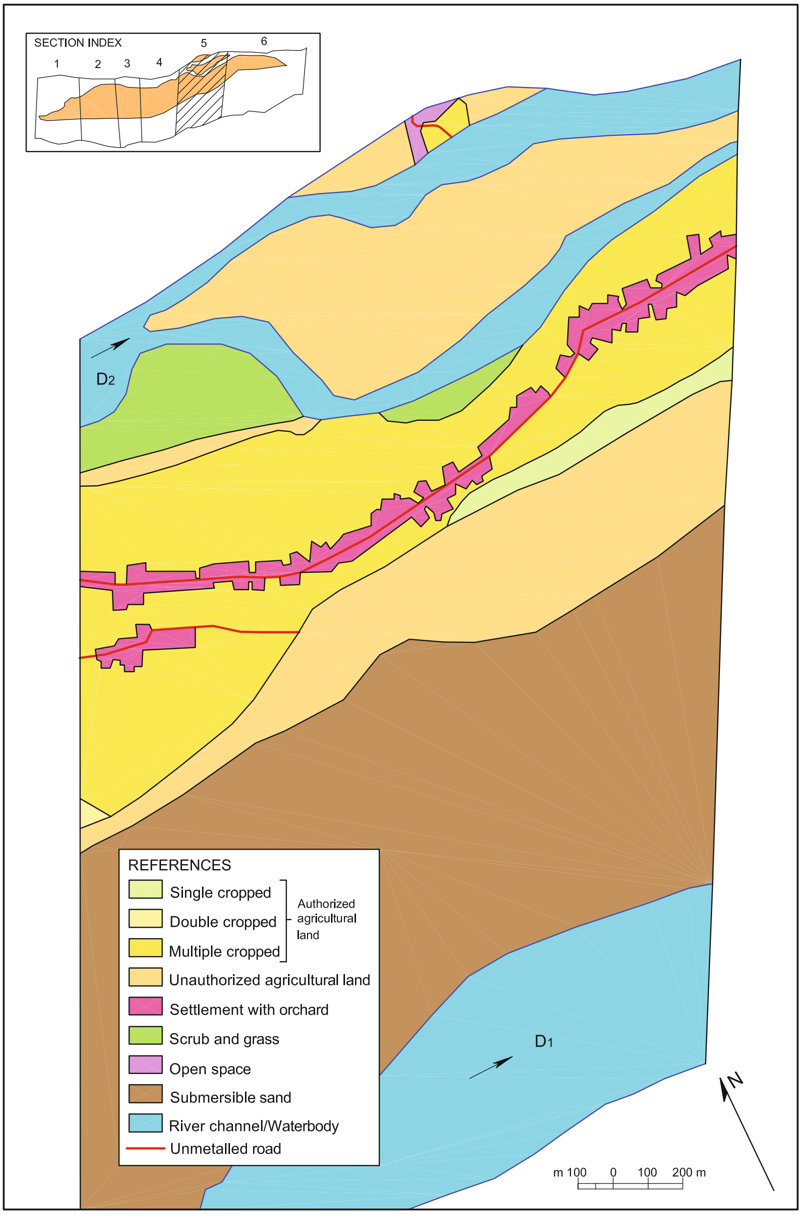

Fig. 6.17 Bara Mana (Section-5) land use characteristics: Pakhanna Radhakantapur and Gopalpur Mouza
Map prepared through active field survey, Pakhanna, Radhakantapur and Gopalpur Mouza maps, SOI 73M/7 (1:63,360, 1: 50,000 & 1: 25,000), satellite image (2003) has been consulted

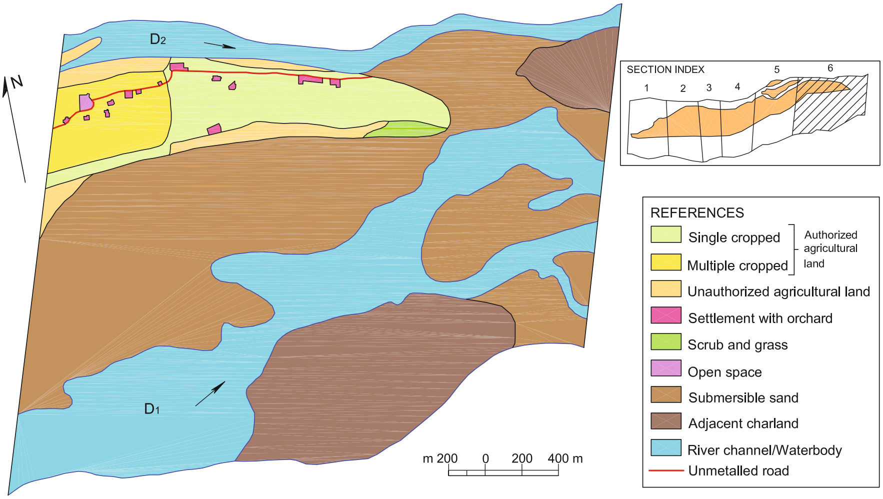

Fig. 6.18 Bara Mana (Section-6) land use characteristics: Palasdanga, Joynagore, Alampur and Dihipara Mouza

Map prepared through active field survey, Palasdanga, Joynagore, Alampur and Dihipara maps, SOI 73M/7 (1:63,360, 1: 50,000 & 1: 25,000), and satellite image (2003) has been consulted

Land utilization in Bara Mana shows an amalgamation of culture inherited from forefathers of the riverbed occupiers and culture acquired from other sections of the same community. The Bangladeshi refugees, used to rice and jute culture in their active deltaic habitat in Bangladesh, introduced these crops to their new habitat which happened to be in an active riverbed. The crops they have introduced at the commercial level are potato and mulberry. Potato cultivation, a part and parcel of Barddhaman and Hooghly culture, has been acquired from the locals. Potato cultivation requires constant vigil and on-site production cost is high. It is therefore grown in the vicinity of settlements and on inundation-free higher areas. Mulberry plantation together with cocoon rearing is also an acquired culture. Bankura and Bishnupur in the district of Bankura are noted for traditional silk. So are Maldah and Murshidabad in the district of Maldah and Murshidabad. These districts provide ready markets for the mulberry cultivated in Bara Mana. Like potato, mulberry, a perennial tree-crop, is expensive and is grown on the highest part of the bar which remains above water level throughout the year (Bhattacharyya 1998, 2009).

Awareness of inundation hazards is clearly evident in selection of settlement sites and use of building materials (Plate 6.7a, b, c). Although the main settlements are away from the thalweg, the bar remains exposed to floods if discharge from the barrage is above 5,664 m^3/s. During the 1978 and 2007 floods, with a peak flow of 9,345 and 7,808 m^3/s at Durgapur, the sandbar was submerged but the settlements were not totally washed away as the individual huts are on higher plinth and bamboo structures, deeply imbedded in the surface, can withstand flood currents. Individual rooms within the houses are equipped with high shelves for storage of valuables.

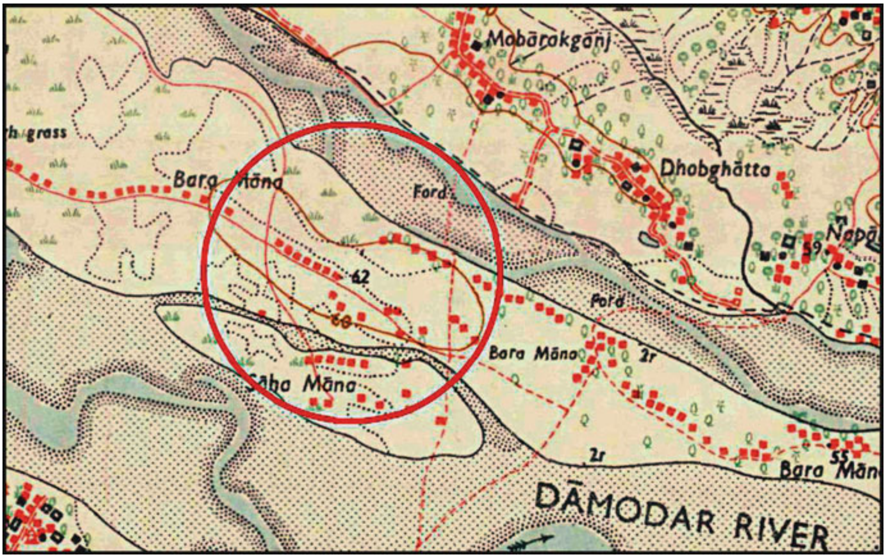

Fig. 6.19 Tajpur and Pakhanna-Bhairabpur in SOI map
Map prepared from SOI 73 M/7, scale, 1: 50,000.

This Sections 3 and 4, including Tajpur and Pakhanna-Bhairabpur (*circled in red*), are bounded with a 60 m (mean sea level) contour with 62 spot height as is shown on SOI map surveyed in 1970.

Communities take shelter here during high flood years. They perceive which parts of the bars will be inundated if water is released from the reservoirs and also whether their new niche would be inundated or totally destroyed during floods

The floods of 1978, 1995, 1999, 2000, and 2007 have improved the adaptive skills of the settlers. The planting of branching perennial tree crops such as mangoes and jackfruit after the 1978 flood serves a dual purpose. The fruits are consumed or sold at local markets and the trees provide shelter during floods in a region where, unlike the deltaic rivers, boating is hazardous (Basu 1988; Bhattacharyya 1998). In the floods of 1995 with a peak flow of 8,495 and 6,522 m^3/s, and in 2007 floods with a peak flow of 7,808 and 8,883 m^3/s from the Durgapur and Rhondia respectively, the bar was submerged in most places. People took shelter on these trees and on higher ground or on school ground, or temporarily deserted the inundated area (Bhattacharyya 1998, 2009).

Accessibility to market is important but more important is the use of market facilities. The emphasis on all types of vegetables, including highly perishable leafy vegetables, is due to market facilities at Durgapur and Panagarh, Pakhanna and Sonamukhi. Initially, the refugees used to be treated as parasites by the locals. But this parasitic relationship has been replaced by complementary and competitive relationships. Control structures have brought about several changes in the riverbed morphology and it is evident that the functional relations of the riverbed with its occupiers have changed more due to change in production relations. What was once a self-supporting closed system is now a more open system with co-action and interaction with local people (Bhattacharyya 1998, 2009).

As far as the social space is concerned, the position of the refugees has not changed much on the horizontal scale, but on the vertical scale their economic status has improved and now they employ locals as laborers. Islanders have been granted ownership rights so they take immense care to stabilize the bar so that monitored release of water from the barrage cannot wash away their self-sought habitat. They have extended their resource base horizontally by using all available land, and vertically as well through multiple cropping (Bhattacharyya 1999–2000b, 2008b, 2009). In addition, they have been granted land deeds despite opposition from the DVC authority. Thus, what was once a group of mobile bars is now a static landform in a controlled riverbed within a graded time period. Finally, the land use characteristics have become viable parameters to assess microforms, processes and materials and inter-relationship between physical and selected components of cultural landscape. The diagrammatic Fig. 6.20 is a generalized model showing the inter-relationship between physical and selected components of cultural landscape.

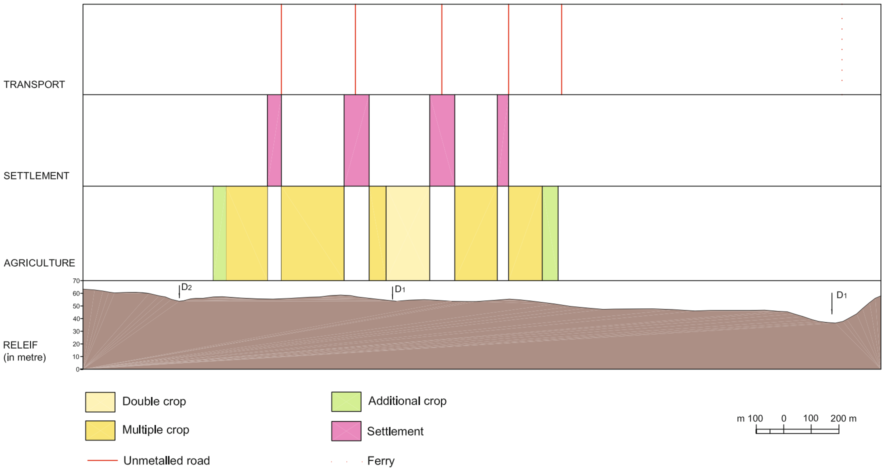

Fig. 6.20 Generalized model showing relationship between physical and cultural landscape

6.3.6 *Rangamatia-Kenety Mana*

Rangamatia-Kenety mana is under the Sonamukhi Police Station of Bankura district. It is under the mouzas of Rangamatia, Kenety, and some portion of the Nityanandapur mouza. In this particular bar, the width of the Lower Damodar is about 2.5 km in comparison to 0.7 km upstream of the Damodar bridge site and 0.5 km below the bifurcation point of the Mundeswari and Amta channel. There are three sandbars. One is the Uttar Rangamatia sandbar, the second is the Dakshin Rangamatia Kenety and some part of Nityanandapur (R.K.N) sandbar, and the third is a small bar yet to be permanently settled. All these sandbars are situated in the dam area of the Rhondia weir (Fig. 6.21). The nearest town and railway station is Panagarh.

The changing boundaries of R.K.N. Mana are shown (Fig. 6.21). In 1920, there were only fragmented transient sandbars. By 1957, despite shape distortion and size reduction in some portions of the bar, land was added to the existing bars. Some new bars also appeared towards the left bank. The 1978 floods caused extensive damage to these bars and they were reduced in size as is evident (Fig. 6.21). The R.K.N. boundaries from 2003 LISS-3 scenes of the IRS-1D satellite show that the bars have grown in dimension but there are a few pockets of permanent bank erosion on the northern part of south Rangamatia sandbar. The thalweg has changed its position several times between 1921 and 2003 but retains its braided channel pattern. As in the other bars, surface materials vary from sand to clay.

People displaced from the former East Pakistan due to the partition of India in 1947 have settled in Rangamatia-Kenety and in Uttar-Rangamatia Mana. They occupied the area by force in the year 1955–1956 when they were deprived of their dole-sustained existence. Dakshin Rangamatia sandbar is settled mainly by refugees whereas the Uttar Rangamatia is dominated by local residents. A small sandbar just upstream of the Rhondia weir is now being occupied by refugee and local population as well. The number of households in Dakshin Rangamatia-Kenety-Nityanandapur

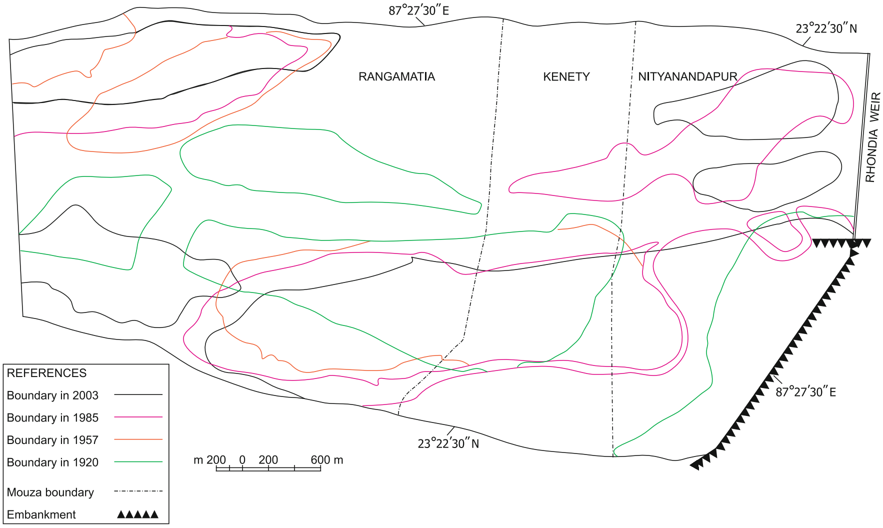

Fig. 6.21 Changing boundary of Rangamatia-Kenety Mana
Maps prepared from cadastral maps, SOI maps, and a 2003 LISS-3 scenes of IRS-ID satellite.

Cadastral Survey (CS) maps, 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. SOI maps of 73 M/7 N.E. 73 M/7S.E. (1:25,000), 73 M/7 (1:63,360, 1:50,000, 1: 25,000) have been consulted sandbar is about 262. The total population is about 1,410. After the devastating flood year of 1978, people from Khanakul in the Mundeswari river of Hooghly district and from Ghatal of Medinipur district came to the Dakshin Rangamatia sandbar and purchased land from refugees. The number of households in Uttar Rangamatia is approximately 150.

Being situated within the Rhondia weir, the bars are vulnerable to frequent inundation but land use is finely adjusted with the fluctuating water level and is extremely flexible. Flood-prone peripheral areas, particularly in the north, are usually kept fallow. Extreme flood propensity at the margin does not allow for growing of additional crops but that is compensated for by intensive cultivation of rice in the inland areas. Almost all households have shallow tube-well facilities (Plate 6.11a). The sandbars were initially uneven in configuration but have now been leveled for agricultural purposes.

Rice is the main crop in the R.K.N. bar in both the Kharif and Rabi seasons. Jute has been a major cash crop right from the beginning. Almost all types of vegetables are grown in this bar because there is a ready market for them at Sonamukhi in Bankura and at Panagarh in Barddhaman district. Potato cultivation was introduced to the bar by local residents who migrated to it (Fig. 6.22).

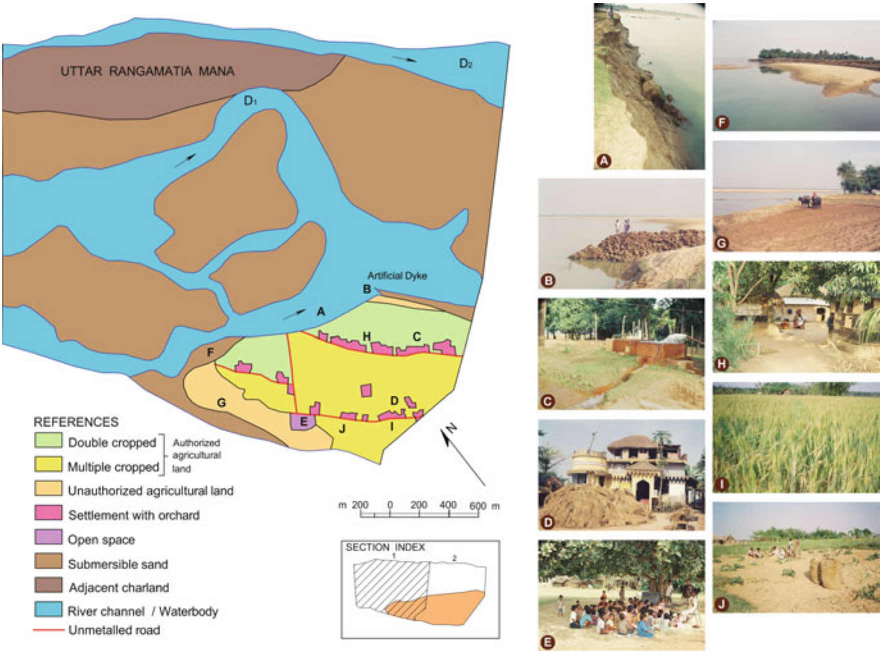

Fig. 6.22 Rangamatia-Kenety Mana (Section-1) land use characteristics: Rangamatia Mouza
Plates: A. Bank erosion at Rangamatia; B. Dyke to prevent bank erosion; C. Irrigation facilities; D. A newly constructed concrete house at Rangamatia Mana; E. Village school at Rangamatia; F. Submersible sand; G. Unauthorized agricultural land; H. Settlement with orchards sited on the highest part of the sand bars; I. Wheat cultivation; J. Potato cultivation

The settlements here are strikingly linear and are located at the highest elevations. They are being extended towards the Bankura side. The shifting of settlement sites from the inundation and bank erosion-prone area i.e. from north to south (Figs. 6.22 and 6.23) is noteworthy. Arquate shape of settlements (Fig. 6.23) in Nityanandapur indicates that they were developed alongside semicircular water channels that have

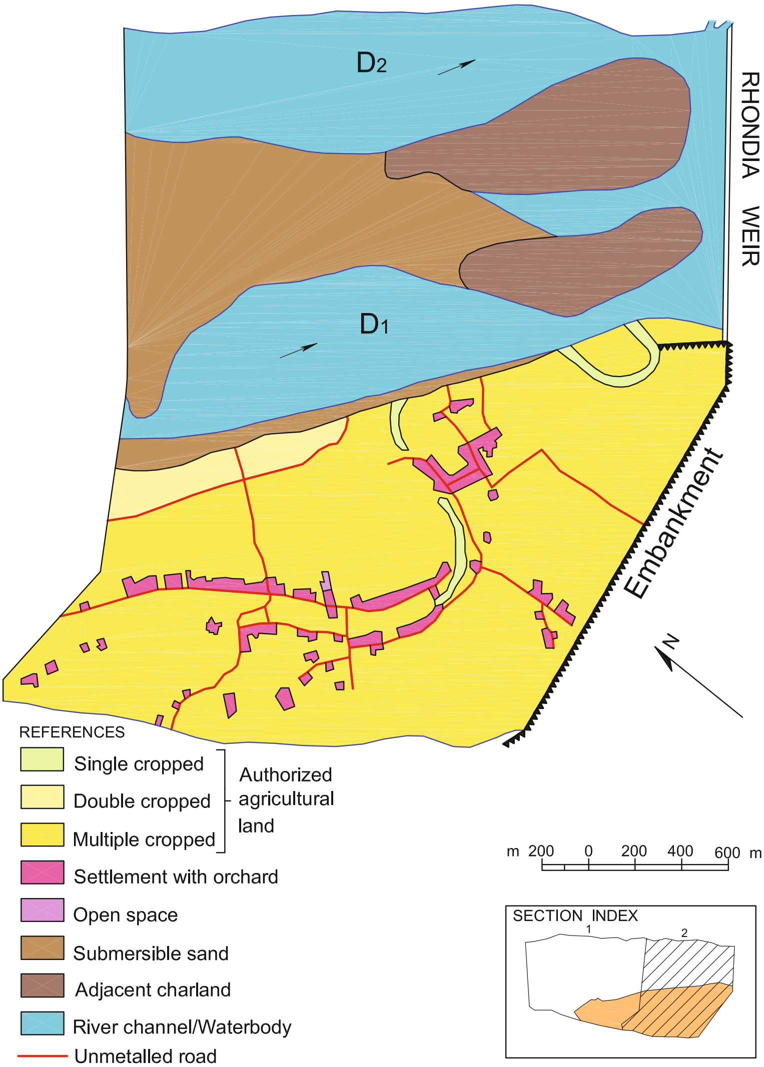

Fig. 6.23 Rangamatia-Kenety Mana (Section-2) land use characteristics: Kenety and Nityanandapur Mouza

Figures 6.22 and 6.23, prepared through active field survey and using several layout plans and cadastral maps (Rangamatia, Kenety, and Nityanandapur) Survey of India (SOI) maps of 73 M/7 N.W., 73 M/7S.E. (1:25,000), 73M/7 (1:63,360, 1:50,000) have been consulted.

nearly dried up. Some such channels can still be seen in the eastern side of the Nityanandapur Mana and are used for rice cultivation. Migrating locals have settled in isolated patches south of the main South Rangamatia Kenety settlements. They purchased land from the refugees and did not have much choice of a settlement site. Their settlement pattern, therefore, is rather amorphous (Fig. 6.23).

Because of high inundation risk, individual houses are constructed on higher plinths above the river water level. Inundation susceptibility is also reflected in the structure of individual buildings made of bamboo and jute sticks plastered with mud and other materials. If there is an unusual flood and the mud is washed away, people remove the bamboo structure to a safer location. In this way they reuse the original structures to construct new houses. Newly constructed concrete structures such as the village school and temple are also found in Rangamatia (Fig. 6.22, Plate 6.11b). The most striking component in the R.K.N. sandbars are the Rangamatia dams or dykes already mentioned.

"Aisab bandher jonno parer kshoy rodh kora jabe abon bandher opore uchhotay o prasthe otirikto jomi paoya jabe". Due to these dykes bank erosion will be arrested and there will be additional land due to vertical and lateral accretion above the dyke, said Binod Das, a well-known farmer, who took the initiative for planning and constructing a series of dykes in Rangamatia. Along the Missouri River in Montana, landowners believed that bank erosion is caused due to operation of the Fort Peck dam (Darby and Thorne 2000). Along the Damodar River, residents believed that operation of Durgapur barrage has initiated bank erosion (Bhattacharyya 1998, 1999).

6.3.7 Fatehpur and Kasba Mana

Just below the Rhondia weir, there is an elongated marginal bar dotted with the settlements of Beloa, Rupuisar, Fatehpur, Amritapara, Beshia, and Kasba (Fatehpur and Kasba Mana). These settlements come under the mouzas of Beloa, Rupuisar, Amritapara, Beshia, and Palsura of Sonamukhi police station under the Bankura district. The nearest town is Budbud and the nearest railway station is Panagarh.

While examining the evolution of the Ramkrishnapalli and Pallishri Colony sandbar, it was observed that the thalweg of the Lower Damodar has shifted from the left bank to the right bank. The same phenomenon is observed in the Kasba Mana. This Mana has nearly merged with the mainland with only a feeble channel, activated during floods, separating this sandbar from the mainland (Figs. 6.24, 6.25, 6.26 and 6.27). Between 1920 and 2003 the sandbar was transformed from isolated fragmented bars to an almost continuous sandbar. Enlargement of the bar is noticed towards the right bank. The evolution of the Fatehpur and Kasba bar from 1920 to 2003 is shown (Figs. 6.24 and 6.25). Notable characteristics include five transient sandbars situated within the braided Damodar in 1920 before the construction of the Rhondia weir. Then, the main thalweg was further north of the present thalweg. By 1957, before the construction of the Maithon (1957) and Panchet reservoir (1959) and the Durgapur barrage (1958) but after the construction of the Rhondia

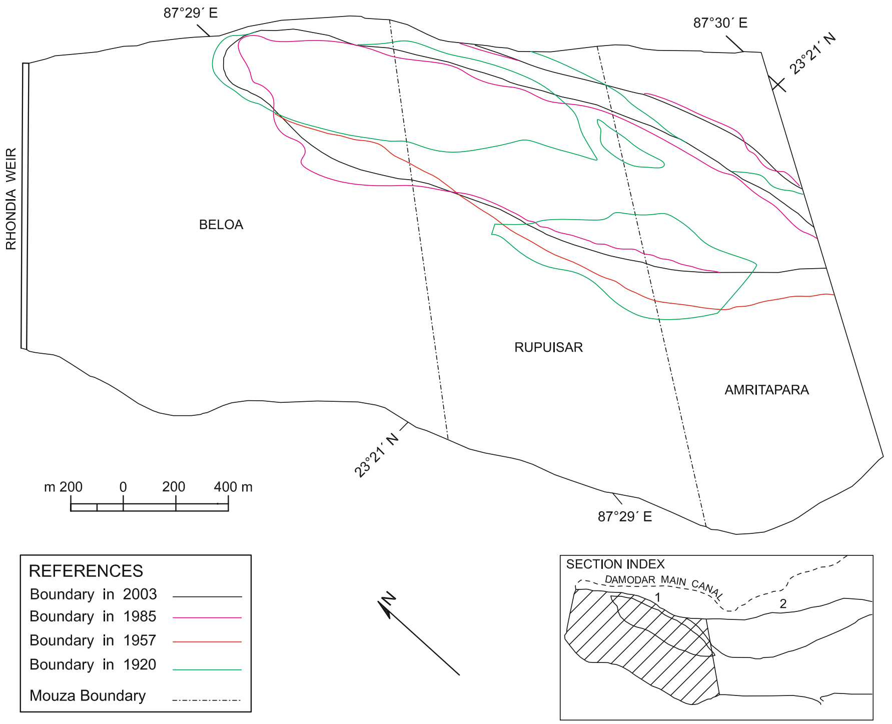

Fig. 6.24 Changing boundary of Fatehpur Mana and Kasba Mana (Section-1)

weir (1933), the two westernmost sandbars had merged together and two eastern sandbars had become continuous. Bank erosion is observed in some areas and the main thalweg has shifted to the right. By 1985 two big sandbars were observed. The channel separating this alluvial bar from the mainland appeared to be dead. Within the period of 1995–2003, the northern part of the Fatehpur and Kasba Mana sandbar had nearly merged with the mainland on the left. Within the bar there were a few channels that are remnants of the previous braided channel and the thalweg has shifted to the south. The right bank line has also shifted further south. This is evident from the 2003 LISS-3 scenes of the IRS-1D satellite.

Transformation of a mobile bar to a fixed bar is a common fluvial process in alluvial channels in their low gradient sectors. It is noteworthy, however, that significant changes have occurred to Fatehpur and Kasba Mana after 1957. It may be presumed, therefore, that detention of water behind the Rhondia weir since 1933 has reduced discharge below the Rhondia weir, creating a sluggish environment in the riverbed conducive to excess sedimentation. There may be a counter-argument that a weir is a local base level that was artificially created, and that river action is renewed below such a base level. It must be mentioned here that release of water from a control structure passes through a definite channel and this definite channel is usually the thalweg. Annual as well as monsoon discharge from the Rhondia weir

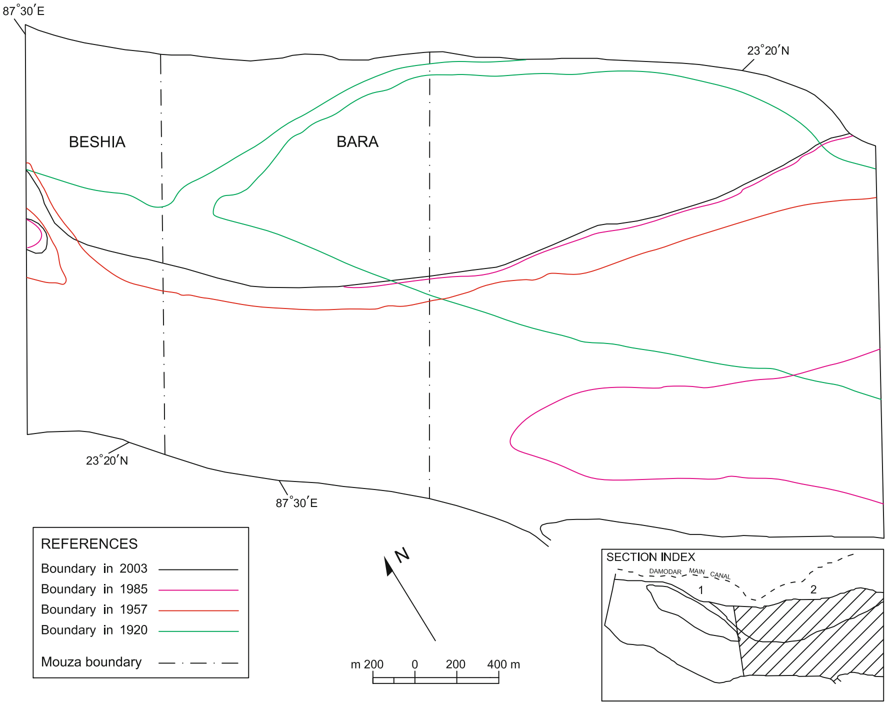

Fig. 6.25 Changing boundary of Fatehpur Mana and Kasba Mana (Section-2)
Maps prepared from cadastral maps (Beloa, Amritpara, Beshia, Bara Palsura, Rupuisar), SOI 73M/10, 73M/11 (1:63,360, 1:50,000), and 2003 LISS-3 scenes of IRS-ID satellite

has decreased (Table 4.3). Reduction in discharge can be attributed to the Damodar main canal which takes off from the Rhondia weir. Therefore, there has been more aggradation than erosion below the Rhondia weir. Construction of a weir in the River Kas, a tributary of the River Mula, Godavari basin, India has also affected the pattern and character of sediments. The Mula-Kas confluence sedimentology is a joint product of flow variability, confluence morphology as well as human activity (Unde and Dhakal 2009).

Between 1957 and 2003 the Fatehpur and Kasba Mana were reduced noticeably. As was noted before, the 1978 flood was considered the greatest disaster in south Bengal in the present century. The severe bank erosion and size reduction of this bar can be attributed to this flood (Figs. 6.26 and 6.27). A new bar, locally known as Chhita Mana, has emerged on the right bank. Bank erosion is still a problem on the right, i.e., on the southern part of the Fatehpur and Kasba Mana.

The Fatehpur and Kasba Mana settlements are dominated by Bangladeshi refugees. A few Biharis who migrated from Bangladesh can be found in the extreme eastern part of the Kasba Mana. The Fatehpur and Kasba Mana are extensively and intensively used by the Bangladeshi refugees. The erosion-prone peripheral area is used for additional crops such as cucumber and different types of melons. The main

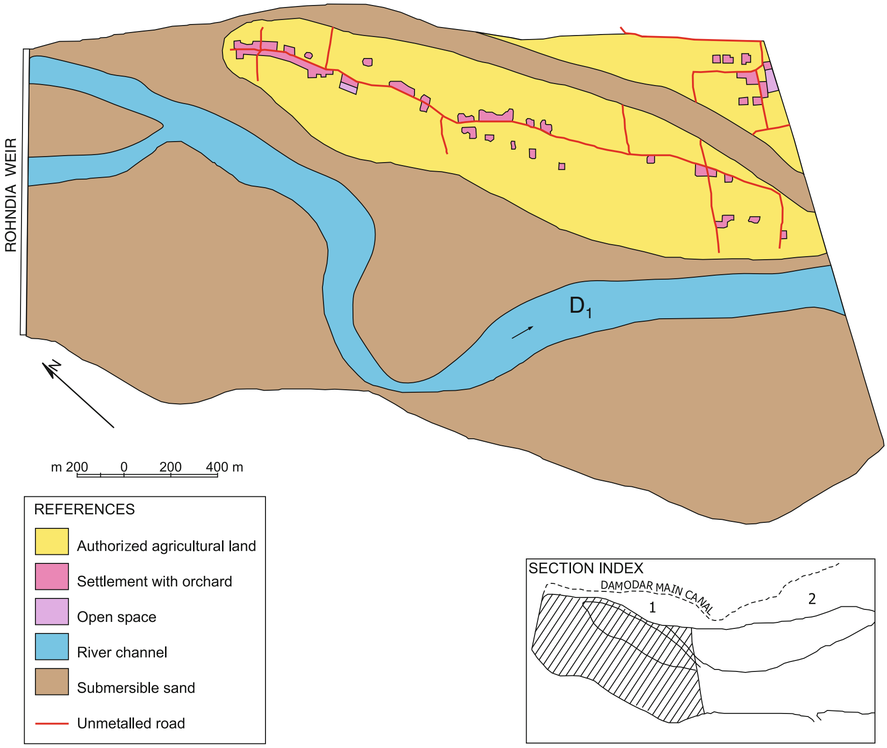

Fig. 6.26 Fatehpur Mana and Kasba Mana (Section-1): land use characteristics
Map prepared through active field survey with layout plans

crops are wet rice and jute. Since 1968, with the help of irrigation, HYV seeds such as *I.R.-8* and *Ratna* have been introduced to the bar. Irrigation facilities from shallow tube-wells have helped in generating wheat culture. Wheat is a more important crop in the Bihari-dominated sector of this bar. In examining the flood and colonization history of the Lower Damodar, we noted that the 1978 flood was followed by large-scale in-migration from Arambag and Khanakul of the Hooghly district to these sandbars. The Hooghly district is noted for potato cultivation, which was introduced to this sandbar by these local migrants. Potato is grown on the higher part of the sand bar. Among oil seeds, mustard is the most preferred crop in this bar.

Unlike Bara Mana, Ramkrishnapalli and Pallishri Colony, settlers on this bar do not grow other perishable vegetables on a commercial basis as the transport link between these bars and nearby urban centers is very poor. Potato is a non-perishable vegetable and, therefore, one of the most important cash crops along with jute. In recent decades, demand for jute has decreased all over West Bengal due to increasing use of synthetic bags instead of gunny bags. As a result, jute cultivation is being replaced by rice culture. Clay deposits accrued from slow vertical accretion in moribund channel beds are used for rice culture. An important

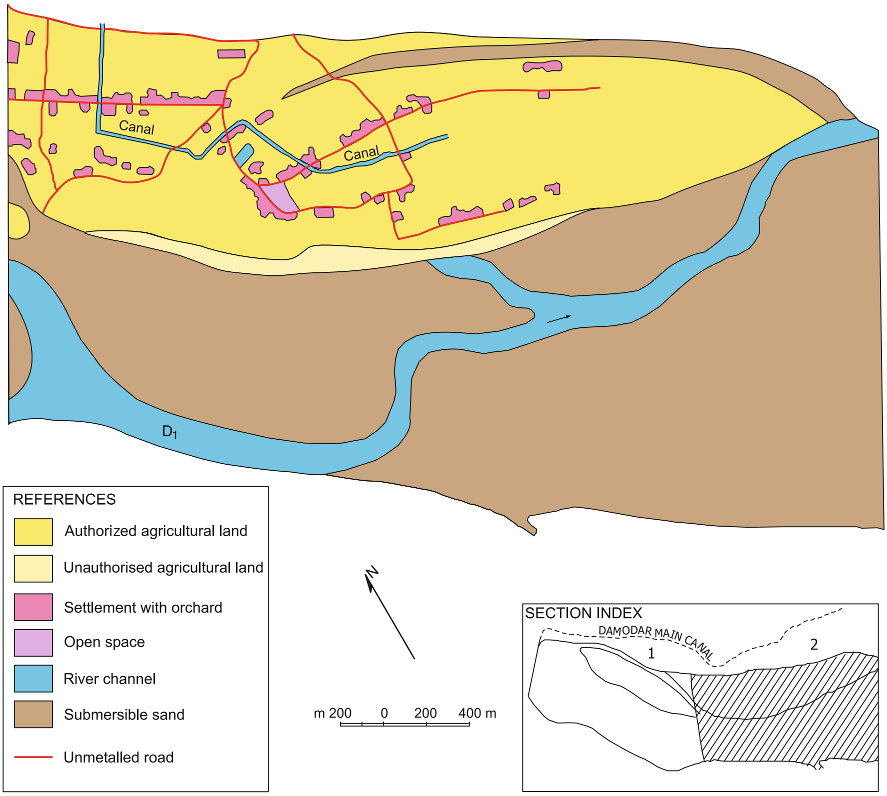

Fig. 6.27 Fatehpur Mana and Kasba Mana (Section-2): land use characteristics
Map prepared through active field survey with layout plans

and striking land use characteristic in the Kasba Mana is a subsidiary canal, which diverts water from the Damodar main canal but ends abruptly near the Bihari dominated part of the sandbar (Fig. 6.27). When the bar was first colonized, settlements were on the south, but the present settlements are to be found in the middle part of the bar. Settlement density is high in Beshia and in the western part of the Kasba Mana. Like other bar settlements, the Fatehpur and Kasba settlements are linear in orientation.

6.3.8 The Stretch Between Chhita Mana and Laksmipur Colony

The section between Chhita Mana and Laksmipur Colony falls under the Patrasayer police station of Bankura. The total length of this section is approximately 10 km. In this section lies the settled sandbar of Chhita Mana and a few other stable bars yet to be settled. On the left bank is Silla from where the left bank embankment can be observed (Fig. 6.28). There are double embankments, enclosing several hamlets,

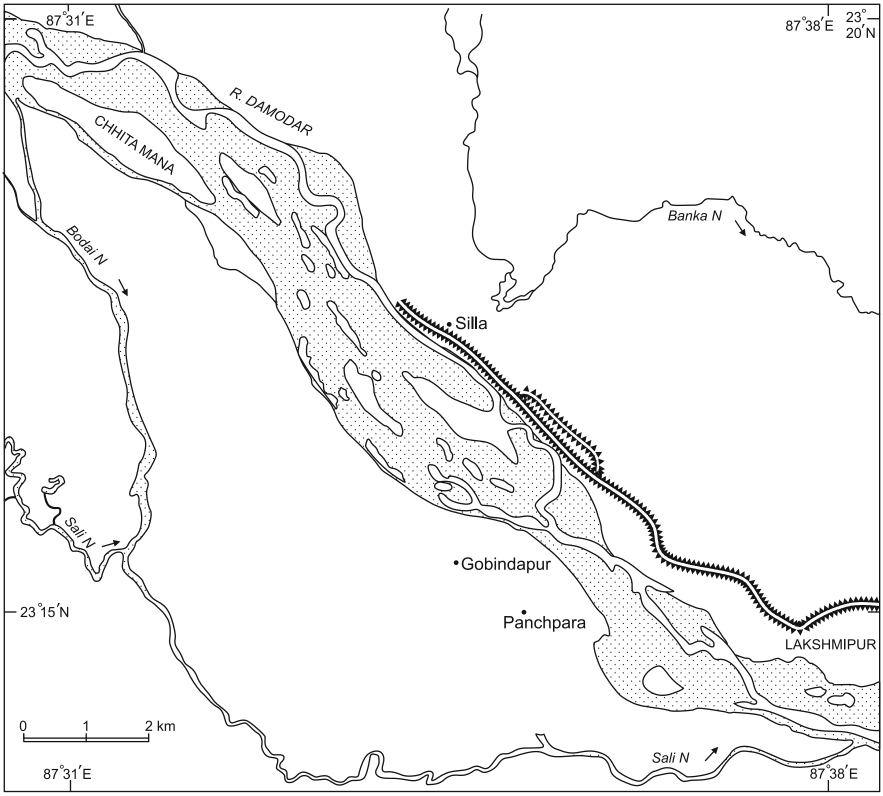

Fig. 6.28 The stretch between Chhita Mana and Lakshmipur Mana
Map prepared from 73 M/11 SOI map (1: 50,000)

between Kashpur and Bikrampur located below Silla. Gobindapur and Panchpara are the two important settlements in this section. They were once part of the riverbed but are now outside the channel boundary. The nearest railway station is Galsi which is quite far from this part of the lower Damodar. The Lower Damodar in this section has thrown several flood-channels on the right bank between Chhita Mana and Panchpara. The Bodai, one such flood channel, takes off at Bhaglui. There are several other linear lakes between Bodai and the main Damodar. These linear lakes may be the remnants of previous flood channels. If we join these linear lakes near Panchpara, we get the previous right bank of the Damodar between Dishinda and Panchpara.

In the SOI map of 1974, Panchpara and Gobindapur have been shown as two independent settlements. At the same time two other settlements named Gobindapur char and Panchpara char have also been shown. Since char refers to sandbar in Bengali, it may be presumed that these two char settlements were sited at the riverbed but now have merged with the mainland (Fig. 6.28). Merging of sandbars with the mainland is also observed in the case of Ramkrishnapalli and Kasba Mana. Between Bhaglui and Gobindapur char, the thalweg has shifted to the north and the riverbed is almost choked with transient bars. Ferry service is restricted between June and November. Otherwise the river, except for the thalweg, is almost fordable throughout the year. Near Panchpara the Damodar is less than 1 km wide, its narrowest width between the Panchet reservoir and Barasul-Chanchai. This is due to merging of previous sand bars with the mainland.

The sandbars between Chhita Mana and Laksmipur Colony are dominated by Bangladeshi refugees who migrated from the government sponsored Bishupur camp. The main Gobindapur and Panchpara settlements, in contrast, are settled only by locals. The main crops are rice and potato. The HYV variety of rice includes *I.R.-36*. As the settlements are far away from major urban centres, vegetables are not grown on a commercial basis. In this respect they can be compared with the Fatehpur and Kasba Mana. The Gobindapur–Panchpara char settlement, like the other sandbar settlements, is strikingly linear as well.

6.3.9 Majher Mana

Majher Mana is a mid-channel bar located below the Rhondia weir under the police stations of Indus and Galsi of the districts of Bankura and Barddhaman, comprising portions of the cadastral maps of Somsar (Indus P.S.), Bhasapur and Sikarpur (Galsi P.S.). The nearest railway station and town are Khana and Gohagram respectively.

In Dickens's map of 1854 a mid-channel bar covered with grass jungles has been shown and is referred to as Baseepoor, which means inundation-prone. By 1929–1930 (SOI map) Baseepoor had merged with the mainland, but a group of small islands had emerged just below it. By 1954 these fragmented bars had been united to form the present Majher Mana (shown in cadastral map 1954, SOI map, 1969–1970). Some significant changes have occurred since 1854 (Fig. 4.14). During the 1978 floods, the eastern part of the Majher Mana was totally destroyed, but enormous amounts of sand were deposited on the western end. The eastern end is still erosion-prone and Majher Mana is still growing to the west (Fig. 6.29). It is separated from the Lakshmipur Mana (previous Baseepoor) by an incipient channel which is fordable in dry months. Lakshmipur Mana is under continuous threat from this incipient channel which becomes torrential during flood years. Sand quarrying from boats is a spectacular activity in Majher Mana (Plate 6.12).

Like other alluvial bars in the Lower Damodar, Majher Mana is settled by Bangladeshi refugees. Like Bara Mana, Majher Mana is an example of the optimum use of every inch of available space, the extent of which varies from year to year depending on the degree of floodability of the char land and irrigation facilities. Land use is thus very flexible. Wild grasses or additional crops of low value are grown on the inundation-prone peripheral zone, while paddy, oilseeds, potatoes and vegetables of high value are grown on higher elevations. Perennial mulberry plantations are to be found together with settlements on the highest part of the bar. The concept of flood zoning is applied here with the spatial extension of each zone, particularly on the bar margin, varying from year to year. Mulberry plantations, however, do not experience flooding as these are sited above inundation level (Bhattacharyya 1998).

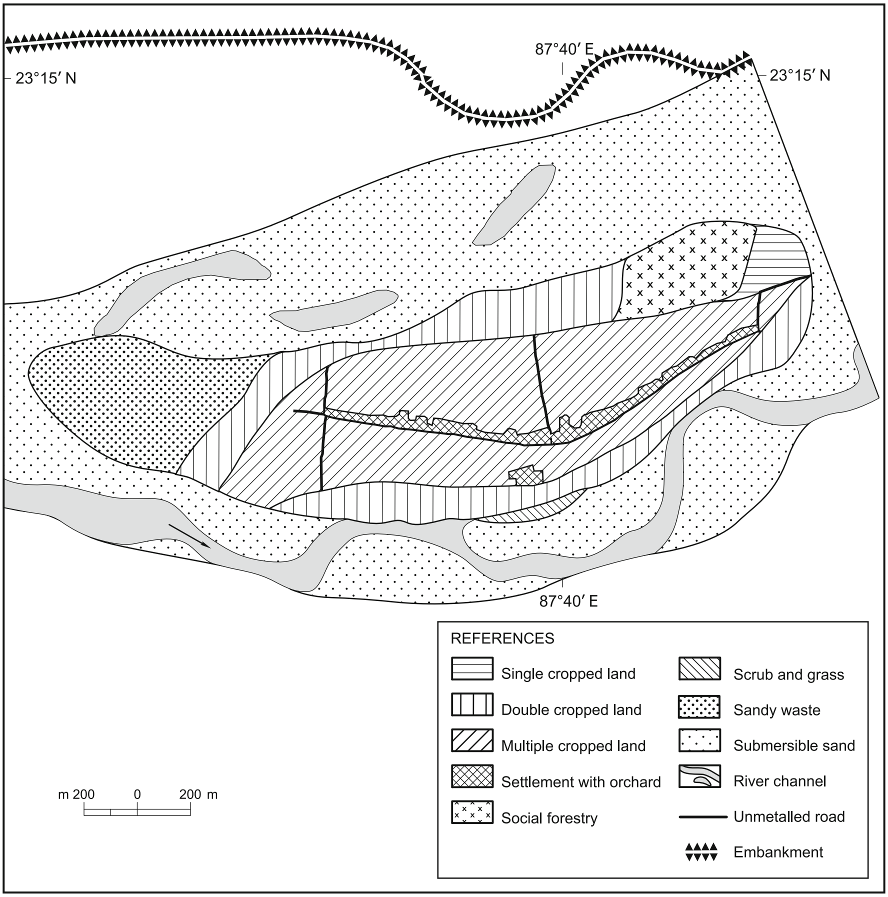

Fig. 6.29 Majher Mana Land use characteristics: Somsar, Bhasapur and Shikarpur Mouza Maps Map prepared from field survey, cadastral maps of Somsar, Bhasapur, Sikharpur of Galsi Police station, SOI (73 M/15/16, 1: 63,360, 1: 50,000), a 2003 LISS-3 scenes of IRS-ID satellite, and from a map of Dickens (1984) are shown

In Majher Mana flood deposits of 1978 and 2007 are being reclaimed for rice, jute culture and additional crops, particularly in the western part. As in the other sandbars, the settlement pattern is linear and individual houses have been constructed on higher plinths. Dried up channel beds are used as roads during the non-monsoon period.

6.3.10 Satyanandapur–Kalimohanpur Sandbar

The Satyanandapur–Kalimohanpur sandbar is sited just below the Jujuti sluice. The nearest railway station is Barddhaman. Bus service has only existed since October 1997. The Baka Nala, a former distributary of the Lower Damodar, flows close to this bar towards the north. This distributary was highly unstable in this area as is evident from the SOI map of 1969–1970. The Banka was highly sinuous and there are several decaying, drying meander scars and flood channels still to be observed. The behavior of the Banka necessitated construction of double embankments with heights of 35 and 26 m. Nowhere in the study area are the embankments so high in altitude. The second embankment is motorable and there is a culvert for passage of Banka water into the river. Dickens's map of 1854 and the SOI map of 1929–1930 show this elongated bar as barren land with a flood channel to the north. At present the thalweg is on the right (Fig. 6.30) though the depth is not very significant and ferry service is only available from November to March.

The Damodar has created several flood channels between the Damodar-Sali confluence and Khalpara. Decaying drying flood channels are still to be seen as disjointed linear lakes. The northern branch of the Damodar just below the embankments is being activated and bank erosion is a major problem for the settlers. The floods of 1978 did considerable damage to the bar as the embankments were breached at several points. Bar materials vary from sandy loam to clay. The Satyanandapur–Kalimohanpur bar is settled by Bengali and non-Bangladeshi refugees and local residents. The non-Bengalis are from Uttar Pradesh. They went to the former East Pakistan from Uttar Pradesh to work as boatmen. After the partition of India they migrated to India together with Bangladeshi refugees. This bar was severely damaged during the 1978 floods with large-scale evacuation of people from the bar to the mainland. The abandoned lands were sold to local Bagdis, a scheduled caste community who keep the lands as fallow as they do not have the means to cultivate them. The main crop here is wet rice. Potatoes and other vegetables have recently been introduced as well after the extension of bus services from Udaypalli to Belkash. Now the emphasis is on high yielding varieties of rice and potatoes. Previously the settlements of Satyanandapur and Kalimohanpur were separated from each other with Satyanandapur close to the embankment and Kalimohanpur nearer to the thalweg. Both the settlements had a linear orientation. This linearity was disturbed by the 1978 floods. A new line of settlements has developed very close to the embankment and a new colony is developing between the double embankments on the left bank. Changing riverbed morphology from Jujuti to Gaitanpur has been shown (Fig. 6.30).

6.3.11 Gaitanpur

Gaitanpur in Gaitanpur mouza under the police station of Khandaghosh is located south of Barddhaman town. The nearest railway station and town is Barddhaman. Dickens's map of 1854 shows Gaitanpur as a marginal bar. In the SOI map of 1930 it appears to be a point bar with the Damodar thalweg towards north but the SOI map of 1970 and 2003 LISS-3 scenes of the IRS-1D satellite show Gaitanpur as a mid-channel bar, but the bar is merging with the mainland as is evident during 2008 field survey. The noticeable change that has occurred is the shifting of the thalweg from north to south. The previous thalweg is used as a flood channel. In the

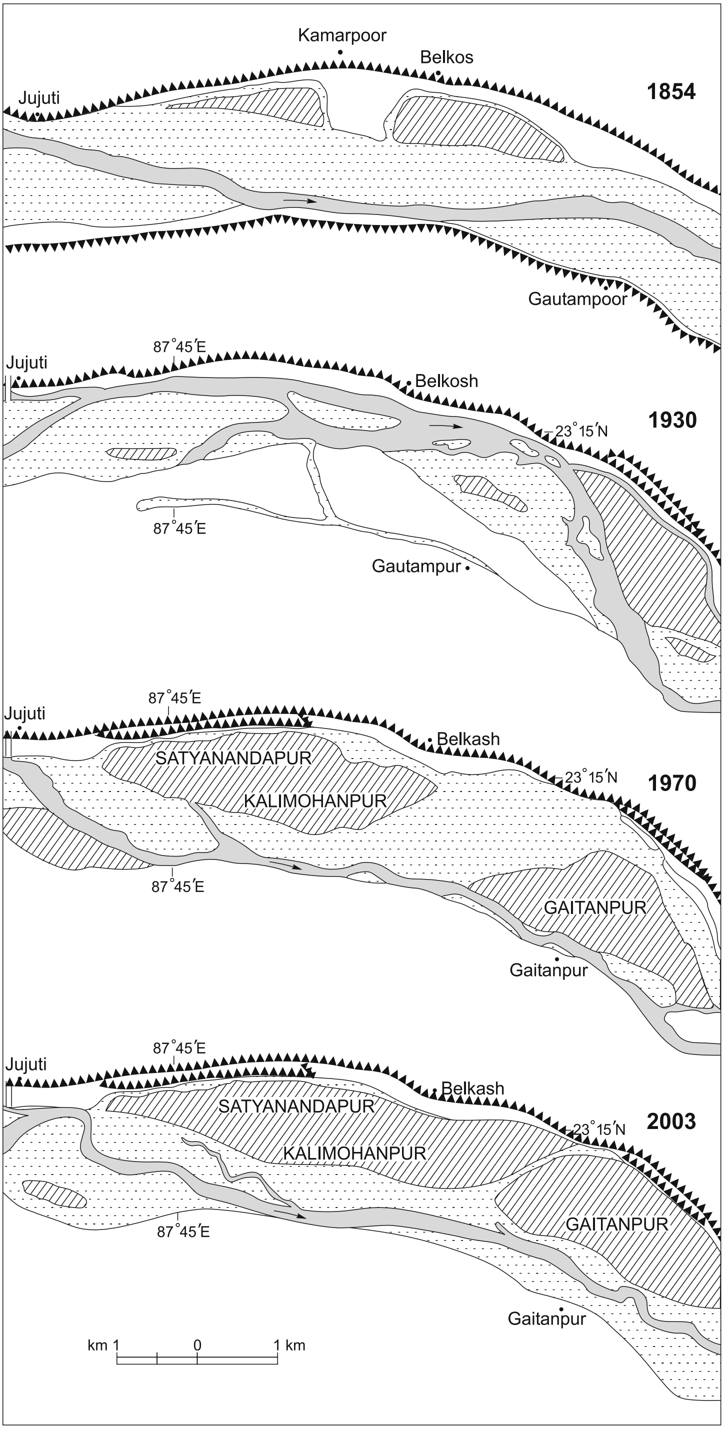

Fig. 6.30 Changing river bed morphology: Jujuti Sluice to Gaitanpur

non-monsoon period, the bed of the flood channel looks like a beaded string with riffles and pools. Another observable feature is the double embankments towards Barddhaman that are indicating the erosive capacity of the old thalweg during floods (Fig. 6.30). The total population in the sandbar is approximately 260 with Biharis dominating. Surnames such as Chowdhury and Nishad indicate that they were fishermen by profession. Therefore, when they migrated from Bihar around 1952 in search of jobs, they preferred a riverine location. Though the number of Biharis has decreased, they are still the majority group in this sandbar. Recent residents include the Bangladeshi refugees who settled here after the Bangladesh war of 1970. It may be presumed that Biharis were initially employed as village watchmen and gatekeepers by the Burdwan Raj and that they were given landed property during the period of the Burdwan Raj.

The floods of 1978 not only remarkably reduced the Gaitanpur bar in size, flood-borne sands nearly covered the landscape and made an extensive area unfit for cultivation. The floods of 1995 and 2007 have again activated the flood channel and extensive protective measures have been taken. Fresh sands that were used to support guava orchards have now been consumed by recent floods. Cattle rearing is a preferred occupation among Biharis. So grasses on fresh sands are used as grazing grounds and almost all houses have cattle sheds (Plate 6.13).

Since Barddhaman is noted for three types of sweets, Sitabhog, Mihidana and Langcha, there is a market for cow and buffalo milk. There is also a market for beef. Barddhaman was under Muslim rule from 1200 to 1650 A.D. (Choudhury 1991) and there is a sizeable number of Muslims in the town and in adjacent areas (850,951 approximately). Hindu Biharis do not consume meat and Muslims use the market facility to sell beef in the town. Apart from cattle rearing, Biharis grow wheat whereas Bengalis opt for paddy culture. As the bar is vulnerable to flood havoc, quick-growing paddy species like *1000, 10; 1000. 11; 1000, 12; Pankaj and Lalsarna* are selected. These species can withstand inundation for 4–5 days. With the lowering of river level just after the monsoon, the first crops grown are mustard. The exposed bed of the decaying flood channel is also used for quick-growing vegetables and oil seeds.

Heaps of fresh sand are still to be found in Gaitanpur. Sometimes these sands are put to agricultural use by applying an indigenous technique. A series of holes are made with an iron cone to reach the clay layer beneath. The holes are then filled with fertilizer and covered. The seedbed is then prepared. Using this technique

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Fig. 6.30 (continued) The maps drawn from the Survey of India (SOI) maps of two series (73 M/15/16, 1: 63,360, 1: 50,000), 2003 LISS-3 scenes of IRS-ID satellite, and from a map prepared in 1854 by Captain Dickens. Calcutta, at a scale 1: 126,720 are shown.

This shows changes in the river between 1854 and 2003. In 1854 the river occupied a portion of the area divided by semi-transient unvegetated bars. By 1930 several migratory char lands are seen covered with grass and xerophytic bushes. By 1970, the main flow is on right side and diminished, the stream flow has been divided by stabilized char lands covered with agricultural fields and settlements. People have occupied these sand bars. In 2003, the sand bars are getting enlarged and merging together roots can draw required nutrients from impermeable clay layers. This technique is applied by the Biharis only. In recent years potato has been introduced to the bar together with floriculture. Marigold is grown using the dew irrigation technique. An occasional cold wave in winter, though hazardous to potato cultivation, is suitable for flower culture. Settlement-wise there are two distinct colonies, the Bihari colony and the Bengali colony. The same linear pattern seen in other bars is repeated in this bar.

The above discussion makes clear how the same resource base is perceived differently by different cultures and how resource scarcity initiates reutilization of a defunct resource. In Gaitanpur bar, floriculture has been introduced to supply the urban area in nearby Barddhaman town (Bhattacharyya 1998).

6.3.12 Fakirpur Sandbar

Fakirpur is a tadpole-shaped marginal bar south of Barddhaman (Fig. 5.2). This is the last important settled bar above the Barsul-Chanchai flexure. Below Fakirpur the Damodar narrows down and there are several transient bars. Fakirpur is well connected with Barddhaman town. Fakirpur is separated from Gaitanpur by a flood-channel and this flood-channel is still observable up to Sadar ghat. The channel is activated in every rainy season. Fakirpur is protected by an embankment towards Barddhaman. The main thalweg is on the right bank. The Eden canal runs almost parallel to the embankment towards southeast of this bar. Lateral movement of the flood channel has now been protected by boulder pitching and a second embankment has been raised.

The Fakirpur sandbar was severely damaged in the 1978, 1995 and 2007 floods, since the low embankment could not provide enough protection. The surface material varies from pure sand to clay. These clay deposits are associated with the dried up parts of the flood-channel.

This bar is settled by Biharis who have migrated to it and by local residents. Initially, a mango orchard owned by locals was probably forcibly occupied by Biharis but ultimately the Biharis purchased land from the locals. There is a striking absence of Bangladeshi refugees. It must be mentioned here that the number of refugees in the riverine sandbars decreases noticeably as one approaches Barddhaman town. It may also be noted that the number of Biharis increases simultaneously.

This tract is intensively cultivated by locals and Biharis as well. Cattle rearing is an important occupation and is generally pursued by Biharis. Fresh sands are quarried and lorries ply right up the main thalweg. Unlike those in other sandbars, the Fakirpur settlement is not linear. Its shape is rather amorphous towards Idilpur and Kathgola ghat. There is another group of settlements towards Sadar ghat. Siting of settlement is controlled less by morphometric property of the bar than by connectivity with the town of Barddhaman. Between these two enclaves there is an extensive area yet to be settled.

6.3.13 Shrirampur to Chaitpur

Longitudinal marginal sandbars between Shrirampur and Chaitpur are within Shrirampur, Hatsimul, Kanthalgachi and Chaitpur mouzas under the police station Barddhaman. The nearest railway station is Saktigarh. Barddhaman is the nearest town.

In Dickens's map of 1854, these bars were shown as well defined point bars without any vegetal cover. There were embankments on the left and right as well. The SOI map of 1919–1920 shows the same bar as grass-covered fragmented bars. From the SOI map of 1969–1970 and 2003 LISS-3 scenes of the IRS-1D satellite the fragmented bars have been shown as a continuous bar with the left bank embankment (Fig. 6.31). Figure 3.11 shows:

i. A dried up channel with the Damodar right bank embankment
ii. Shifting bank lines between 1984 and 1990
iii. Boulder pitching, a protective measure to arrest shifting bank lines
iv. A point bar on the right bank.

This stretch is not settled. The fresh sands are used in two ways, sand quarrying and growing vegetables that require a short growing period. The dried-up channel bed is also used for such vegetables in non-monsoon periods (Fig. 3.11). Growing of vegetables depends on the field capacity of fresh sand which is usually low. On the western side there is a small settlement. Contemporary land use shows how a flow resource has been replaced by fund resources.

6.3.14 Chaitpur to Kalinagar

The area is situated above Palla where the Lower Damodar takes a sharp southerly bend. It is located to the south-east of Barddhaman. The nearest railway station and town is Barddhaman. The Dickens's map of 1854 shows embankments on both sides. The SOI map of 1919–1920 shows the left bank embankment only but the SOI map of 1969–1970 and 2003 LISS-3 scenes of the IRS-1D satellite shows double embankments on the left. The thalweg is on the left (Fig. 6.31).

The area has been resurveyed by the Irrigation and Water Ways Department of West Bengal. The layout plan (Fig. 3.12) of the Damodar near Fatehpur village under Jafrabad mouza shows the following features:

i. Towards east the bank line has shifted between 1978 and 1985
ii. The thalweg is still on the left side
iii. Several sandbars have been formed which are only 27 m above the the water level at their highest points.

From the field survey it is observed that the left side has become erosion-prone; therefore, protective measures such as boulder pitching have been taken since 1990.

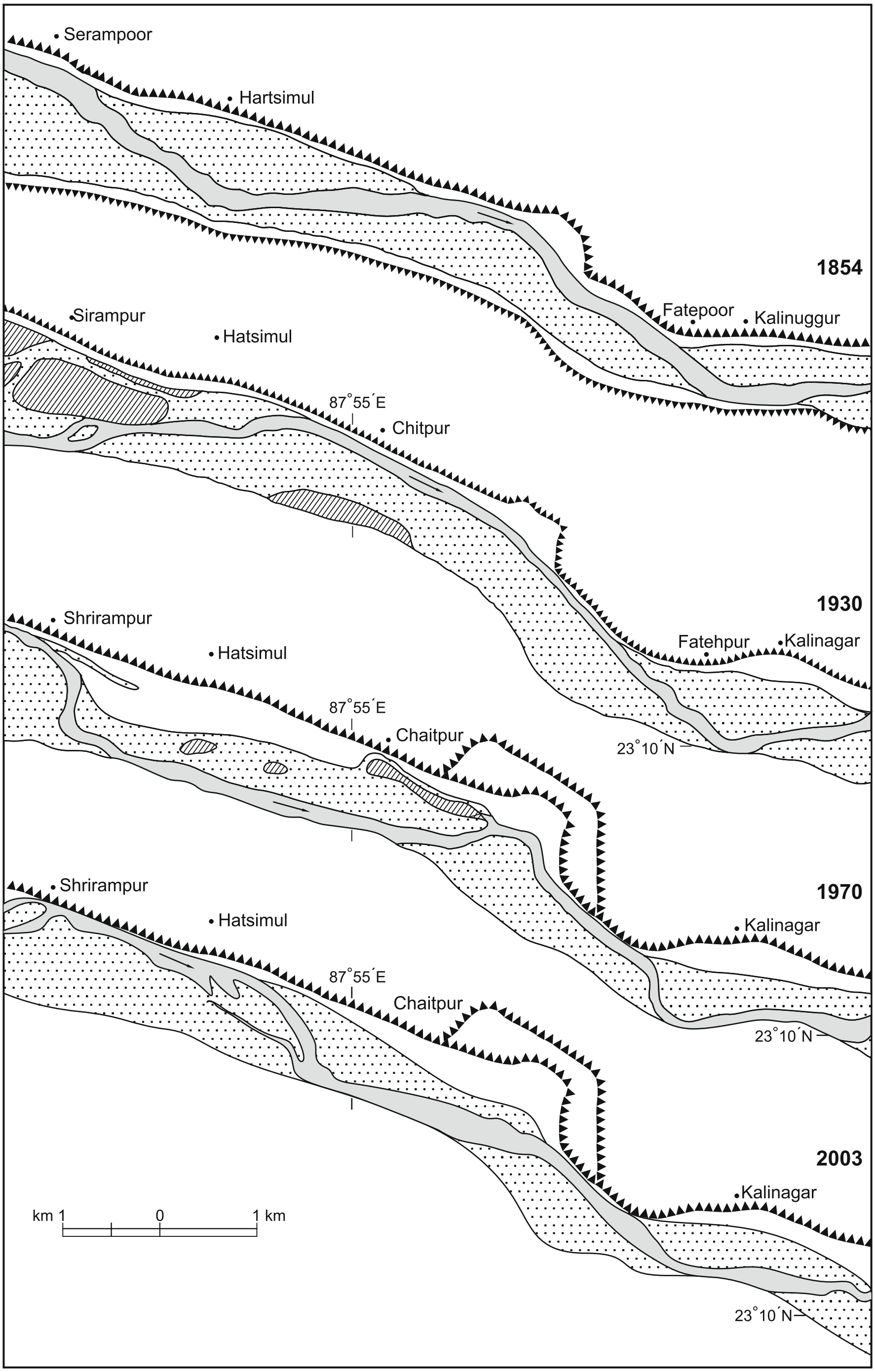

Fig. 6.31 Changing river bed morphology: Shrirampur to Kalinagar
The map drawn from the Survey of India (SOI) maps of two series (73 M/16, 1: 63,360, 1: 50,000), a 2003 LISS-3 scenes of IRS-ID satellite, and 1854 map of Dickens is shown

On the unprotected right bank there was a spill channel locally known as Mohanpur Hana but the off-take point of this spill channel has been sealed off to protect the adjacent riparian tract from floods. The sand bars are yet to be stabilized; therefore, no permanent settlement is found. Locals from adjacent villages use the riverbed between the bank line of 1978 and 1985 for paddy and potato cultivation. Mustard is also grown. Fresh sands from mobile sandbars are quarried by the locals.

6.4 Human Perception, Adaptability and Resource Evaluation in the Riverbed

Sandbars that were perceived as unproductive by the local agrarian community were seen quite differently by refugees due to their distinct position in the social space. Although there are fewer floods in the post-dam period, sandbars still get inundated, at least partially, whenever excess water is released from the reservoirs. The refugees have accepted this flood risk and have taken some pragmatic measures in their own land use system which is flexible and adjusted to the flood-prone micro-environment. At present all available space on the sandbars is being used objectively and rationally. As human perception and the appraisal of environment has changed, the concept of resource evaluation has widened (Bhattacharyya 1997, 1998, 2009).

In Gangtikali, there has been a shift of resource base from geological to agricultural with a consequent change in settlement site. As the occupiers are Biharis, their preferred foods, wheat and maize, are the most important crops grown on the island. Because of higher elevation, release of water from the Panchet is not considered hazardous. Instead, it raises the water level, thus helping to lift irrigation.

Flood risk is low in the main area of Telenda mana, as the main flow of the Damodar is far away from the settlement. Wet rice and jute were introduced first as major crops, followed by two other important crops, wheat and potatoes. On the periphery of Telenda mana, quick-growing additional crops are grown on the nutrient-poor fresh sands which are exposed after lowering of the river water level. The riverbed of the Gaighata is used for additional crops. A new Vivekananda colony has developed towards the Panchet side.

The sandbar in Damodar Char Mohana is highly inundation-prone. Land use on this bar is flexible with spatio-temporal variations in land use attuned to spatio-temporal variations in inundation. Settlements and perennial tree crops are to be found on the highest part of the bar. Inferior crops and vegetables are grown on the flood-prone peripheral zone. The concept of flood zoning has been applied here at a micro level. Crops grown vary from cereals to cash crops that include potato and chilli. Extraction of sands from the dead channel on the left has deepened the channel, posing a threat to the stability of the bar. Refugees on this bar have been granted land deeds despite the vulnerability of the area.

Ramakrishna Palli, Pallishri Sqatters' colony, and Sitarampur Mana are situated on a marginal bar, a former active riverbed that has nearly merged with the mainland due to the southward shift of the main Damodar. A few decaying, drying channels, including the previous thalweg, are still visible. Here, inundation risk is low due to controlled release of water and the emergence of a transient bar south of the main bar. This bar was inundated but not totally destroyed in the 1978 floods. Surface materials in the bar vary from sand to clay deposits in the dried up channels. Along with rice and mesta, different types of vegetables are grown in Ramakrishna Palli, Pallishri, and Sitarampur Mana.

Bara Mana, the largest alluvial sand bar in the culturally defined Lower Damodar, has grown in size since 1920 and this enlargement has become more noticeable since 1957. Bank erosion is a perpetual problem in Bara Mana, particularly towards the barrage and weir side. The main thalweg is on the right. Other channels have either dried up or are in a moribund state. The 1978 flood submerged the bar but did not totally destroy it. Every inch of land in Bara Mana is put to agricultural use with crops varying from traditional rice and jute to different types of pulses, oil seeds, vegetables including potato, and mulberry, a perennial tree crop. Land use is flexible and flood zoning is attuned to micro relief variations (Figs. 6.14 and 6.16). Additional crops of different types of gourds and melons, including "khero" which requires little care and can be grown profitably on nutrient-poor fresh sands, are grown on the inundation-prone peripheral zone. Settlements, mulberry plantations, and floriculture are sited on higher ground. Settlement sites, structures of individual huts, and plans of individual rooms are adapted to the flood susceptibility of this mid-channel bar. Changes in settler relations with local residents, strong market forces and granting of ownership rights have influenced land use and contributed to changes in riverbed form, processes and materials.

Being situated within the Rhondia weir, the Rangamatia-Kenety mana bar is extremely inundation-prone. Between 1920 and 2003 the bar has shown shape distortion due to size reduction and enlargement of the bar in different parts. The bar was submerged and severely damaged during the 1978 floods. The thalweg has shifted to the south but retains its initial braided channel pattern. The R.K.N. bar contains some permanent pockets of bank erosion.

Surface materials vary from sand to clay. Locals migrating from the districts of Hooghly and Medinipur after the floods of 1978 have changed the population composition of the refugee dominated R.K.N. Mana. Rice and jute have been extensively cultivated on the leveled inner zone from the very beginning of habitation. Due to accessibility to Sonamukhi (Bankura) and Panagarh (Barddhaman), almost all types of vegetables including highly perishable leafy vegetables, are grown. Potato cultivation has been introduced by migrating locals. The inundation-prone peripheral area is usually left fallow. Linear settlements of refugees on higher ground stand in contrast with the isolated homesteads of local migrants. New settlements have sprung up in the south, far away from the permanent bank erosion-prone area. Movable bamboo structures are used to build individual houses that are constructed on higher plinths. People here believe that Rangamatia dykes, a local effort, may reduce bank erosion and help in partial reclamation of inundation-prone land (Fig. 6.22).

From a group of sandbars in 1920, the Fatehpur and Kasba Mana has become a continuous longitudinal bar. Noticeable size reduction has been observed between 1957 and 1985 due to severe bank erosion during the 1978 flood. The thalweg has shifted to the south. There is a feeble channel between Beloa, Rupuisar and Fatehpur, Amritapara, Bhesia. The northern part of the sandbar has nearly merged with the mainland. After 1957, a portion of the mobile riverbed, locally known as Chhita Mana, became stable southeast of the Kasba Mana. Bank erosion is still a noticeable feature towards the right bank. The sandbar is settled by Bangladeshi refugees, Bihari refugees, and local residents who have migrated from the Hooghly district. Wet rice and jute were introduced to Fatehpur and Kasba Mana first by the Bengalee refugees. Decaying drying channel beds are used for rice culture. Since 1970, the extension of irrigation facilities using shallow tube-wells has made it possible to grow HYV varieties. Additional crops such as different types of cucumbers and melons are grown on the periphery of the bar. A small canal, diverting water from the Damodar main canal, has been dug in the Kasba Mana. Perishable vegetables are not grown due to lack of transport facilities. The most important cash crop on this sandbar is the potato, which was introduced by migrating people from the Hooghly district. The early settlement on Fatehpur and Kasba Mana was on the southern side of the bar. The present settlement has shifted northward. Like other bar settlements, the Fatehpur and Kasba settlements also show a marked linearity.

Between Chhita Mana and Panchpara the Lower Damodar has thrown several flood channels on the right bank. Some of the detached flood channels look like a string of linear lakes. The left bank embankments may be observed from Silna. There are double embankments in places.

The Damodar is very narrow near Panchpara because the riverine alluvial bars have merged with the mainland. The riverbed is almost choked with mobile sandbars and the thalweg has shifted to the north. The river is almost fordable from November to June. Rice is the main crop and the only cash crop is the non-perishable potato since there is no easy access to markets. Vegetables are grown for home consumption only.

Majher Mana, a mid-channel bar, is growing to the west and the north. The eastern-most end of the bar was severely affected during the 1978 floods. An enormous quantity of sand was deposited on the western end. Majher Mana is separated from the previous Baseepoor (present Lakshmipur Mana) by a feeble channel. This alluvial bar is dominated by refugees. Land use is flexible and the concept of flood zoning has been applied. Wild grasses or additional crops of low value are grown on the periphery. Mulberry plantations are found on the highest elevations. Social forestry is practiced in the northeastern part of Majher Mana. The 1978 flood deposits are being reclaimed for rice, jute and additional crop cultivation.

The Satyanandapur–Kalimohanpur sandbar has always been flood-prone due to unstable behavior of the Banka nala and so has double embankments of considerable height. The bar is susceptible to bank erosion towards the south. The main thalweg to the right is not very deep. The settlers on the Satyanandapur–Kalimohanpur bar are Bengali and non-Bangladeshi refugees together with a few local residents. Rice is the main crop. Potato and other vegetable cultivation have recently been introduced after the extension of bus services from Udaypalli to Belkash.

Gaitanpur is a flood-prone bar that is at risk from the seasonally activated flood channels. It is settled by migrated Biharis and locals with Biharis being the dominant group. Population composition has changed recently due to inclusion of Bangladeshi refugees. Although agriculture is the main occupation, cattle rearing is given equal emphasis due to demand for milk in Barddhaman. Potatoes, vegetables, and oil seeds have been introduced recently. Floriculture, introduced in 1990s is becoming popular now. The bar was severely damaged during the 1978 floods and its size was reduced. Extensive areas were covered with sands which used to support only grasses until 1990. These deposits have recently been put to agricultural use with the application of an indigenous technique. Despite proximity to Barddhaman town, Gaitanpur, like other mid-channel bars above the Rhondia weir, is not well developed.

Fakirpur is a marginal bar with an active flood-channel towards the north. Due to severe bank erosion to the north, boulder pitching measures have been adopted. The bar is populated by Biharis and locals. Cultivation and cattle rearing are two of the main activities. The bar is noted for sand quarrying. Settlements are located near the main transport route. The settlement pattern is amorphous.

From Chaitpur to Kalinagar, the left bank is shifting in character. Boulder pitching is used to arrest these shifting bank lines. Vegetables are grown in dried-up channels. Riverbed sands are extensively quarried.

The stretch of the Damodar between the Maithon and Panchet reservoir and Barsul-Chanchai is not very much differentiated in terms of contemporary riverbed morphology and bed materials, particularly below the Durgapur barrage. Alluvial bars, mobile, semi-mobile, or relatively static, are general features of the riverbed. Bed materials are fresh sands or sandy loam. But the riverbed landscape, shaped by functional relations between the riverbed and its occupiers, shows diversity at a micro level. Socio-cultural, economic, and political backgrounds of riverbed occupiers have been reflected in the land use practices. Wheat is the main crop in Bihari-dominated sandbars like Ganglikali and Gaitanpur. Rice and jute are two important crops in Bengali refugee-dominated settlements. Bara Mana and Majher Mana show all stages of agricultural development. These two riverine bars are also examples of application of the concept of flood zoning. With increased social mobility and access to local markets, capital-intensive and environ-sensitive crops such as mulberry have been introduced on higher parts of the alluvial bars. Granting of ownership rights in recent years has played a crucial role in land use practices. Refugees take more care to fortify their resource base by applying indigenous techniques. Settlements like Rangamatia and Bara Mana have reached a level of self-sufficiency. This has been possible due to their keen perception of hydro-geomorphological parameters of the controlled river. The stretch between the Panchet Maithon reservoirs and Barsul Chanchai has become less hazardous and more resource-rich with the mitigation of annual flood discharge. Here, risk is capitalized as a resource and long-term benefits have overshadowed the short-term risk (Bhattacharyya 1998, 2009).

6.5 Disaster Reduction Measures and Survival Strategies

The migrant community discovered these riverbed char lands as there was no competition for these sandbars and here they could have an independent existence. They started to colonize these uncharted terrains whose resource potentialities were not identified by the local people. These people with their sense of vulnerability analyzed the physical space more objectively and rationally and looked at it as a challenge to their independent existence. They were forced to live within such a closed system, but this system enabled them to assess the physical parameters of flood more objectively and to adopt innovative measures to reduce hazard loss. Based upon their knowledge of river stages, they have matched land use at fine scales to flood experiences, applying a concept of flood zoning to the riverbed. Every available space has been utilized rationally and judiciously. The inundation-prone peripheral zone of individual bars is left fallow. The wild grasses that grow on sandy soil are used to make rope and some other crude house hold commodities. The next zone is utilized to grow quick-maturing inferior types of vegetables and fruits like bitter gourd, cucumber, and water melons. On relatively safer areas they grow cereals, vegetables like potatoes, cauliflowers, radish, tomatoes and many other leafy vegetables, cash crops like oilseeds, Jute, sugarcane. In some of the bars, mulberry cultivation has been introduced for cocoon-rearing. Perennial fruit trees are common on the highest parts of the bars. Moreover, they often take the risk of growing capital-intensive vegetables even in the most vulnerable tract sas they have ready markets in Durgapur, Panagarh, Sonamukhi and Barddhaman.

The settlements are strikingly linear on the crests of the convex bars. Investment in the construction of houses is very low. As mud is not available locally, the houses are made of locally available jute sticks and bamboo. Almost each house has an upper shelf where they can keep their valuables and take refuge during floods. During high floods they move to the mainland with their mobile population. Spurred by restricted social and economic mobility and sometimes political constraints, islanders have learned to adapt to their vulnerable environment. They have accepted flood risks and have taken some pragmatic measures in their own land use system (Bhattacharyya 1997, 1998, 2008b). They have learned to undertake damage mitigation measures for flood management using an integrated approach. Kundzewicz and Kaczmarek (2000) stated “More disaster-conscious societies need to be built with better preparedness and safe-fail (safe in failure, i.e., system that fail in a safe way), rather than unrealistic, fail-safe (safe from failure, i.e., systems that never fail) designed systems. Since a flood protection system guaranteeing absolute safety is an illusion, a change of paradigm is needed: it is necessary to live with awareness of the possibility of floods”. Thus, looking on the bright side of the floods, they have learnt to underestimate the danger of living in a flood-prone micro environment, therefore, the flood reduction measures specially non-structural measures adopted by these refugees often poses challenges to the technology and capital-intensive measures taken by the governments (Basu and Bhattacharyya 1991; Bhattacharyya 1994, 2008b).

River communities have developed adaptation strategies to live in such a marginal environment. Some of their survival strategies include changing crop patterns, constructing flood resistant buildings on higher ground, planting trees, building settlements on higher plinths above river water level, building inundation-proof structures, and evacuating the areas during high floods. They are also building several dykes to protect their sandbars from erosion. Although the education level of the majority of people living on the sand bars is very low, they are taking measures similar to land use planners; evaluating proper land use in terms of both the potential flood risk and the beneficial natural attributes of the riverine environment (Bhattacharyya 2008b).

Settlers have a definite plan of action which they implement at the time of need and the Damodar river beds are gradually being legally occupied (Bhattacharyya 1998, 1999, 2008b). The main attraction of this "living with floods" approach is that it produces benefits from the normal floods whilst reducing the risks during abnormal hazardous events (Bhattacharyya 2002). To reduce flood hazard, the local population in these sand bars either migrate temporarily to a safer zone or migrate permanently if the economy permits. Instead of fortifying their environment, they depend on aid agencies during calamities. But the same group, when uprooted and attaining refugee status may reject a dole-sustained existence and colonize in barren areas. In the process of colonization they modify and fortify the vulnerable tract and gradually expand the local resource base to reduce hazard loss (Bhattacharyya 1991, 1999).

6.6 Flood Zoning in the Charlands/Sandbars

At the initial stage, the migrant community started devegetation of the sandbars. As they were from the farm sector, they began to perceive the agricultural potentiality of the sandbars and adapted themselves to such tracts with their wet rice culture. "In the past we used this tract as grazing ground. Falling leaves and animal droppings enhanced fertility of the sandbars" – "Amra aage ai jaygay goru mosh choratam,. oder gobor ar pocha patay ai jomir urborota bere gelo" said Bolai Paik, a well known farmer from Bara Mana. Land use in the sandbars follows the dictate of micro-relief. 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

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Fig. 6.32 Generalized crop calendar – a model
The settlements, dotted with perennial crops, floriculture, cocoon rearing mulberry plantations, potato cultivation are sited on the highest part of the sand bars on about 8–10 m above the riverbed.

The zone next to the highest elevations (3–8 m) is devoted to the cultivation of cereals and important cash crops. The Bangladeshi refugees have introduced chilly as an important cash crop to these char lands.

Fig. 6.32 (continued) Fast-growing vegetables and fruits such as poira or additional crops are planted on fresh sands near peripheral zone on about 2–3 m from riverbed level with the lowering of river water level. Height mentioned here varies in different char lands or in same bars according to the differences in width and height in particular char land

tract, as ready markets are present in Barddhaman and Durgapur. In 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 utilization of the local resource base (Basu and Bhattacharyya 1991; Bhattacharyya 1998, 2008a, 2009). A generalized crop calendar model is shown (Fig. 6.32). The crop calendar is finely adjusted to match the flood-prone micro-environment.

6.7 Contemporary Riverbed Characteristics: Barsul Chanchai to Paikpara Settlement

Alternate point bars with a narrow channel are the primary characteristics of the riverbed below Barsul-Chanchai. The SOI map of 1969–1970 shows only the left bank embankment, as the right bank embankment has already been removed. Instead, on the right bank, there are several spill channels of which Nagra hana spill channel merits mention. The riverbed characteristics of the Damodar and its main spill channel, the Muchi hana are shown (Fig. 3.7). Notable features include the fact that the main Damodar is narrower than its spill channel, the Muchi hana, which appears to be a braided channel. The Begua hana connects the Damodar with the Muchi hana which then takes the new name of the Kanki-Mundeswari. The Amta channel is the continuation of the Damodar. The left bank embankment on the river is shown.

The Lower Damodar takes a sharp southward turn from Barsul-Chanchai in accordance with the regional slope of the Bengal delta. Geologically and geomorphologically this section is distinctively different from the section above Barsul-Chanchai. The sudden southward bend is attributed to the lineament characteristics of this part of the Bengal basin. The lineament analysis of the Bengal basin, as inferred from Landsat imagery, shows ten major lineaments and the Damodar lineament is one of them (Agarwal and Mitra 1991). Some other tributaries of the Hooghly Bhagirathi, such as the Mayurakshi, Khari and Banka, show similar trends and these trends are also explained in terms of lineament characteristics (Niyogi 1978).

Geomorphologically, all the rivers show deferred tributary junctions. Had the east west trend of the Lower Damodar continued, the river would have joined the Hooghly far north of the present Falta outfall. It was mentioned before, while tracing the flood history of the Lower Damodar, that this Barsul-Chanchai section is the area from where several distributaries were thrown in the historical past and some of which became the main channel in a specific period. Those channels have dried up, but large and small natural levees and the Palaeo Sub delta (Fig. 6.33a–c) are still to be found (Niyogi 1978; Agarwal and Mitra 1991). From Barsul-Chanchai there has been a gradual diminution of cross section i.e., reduction in the width of the natural river and overall shrinkage of the channel. This section is also conspicuous by an

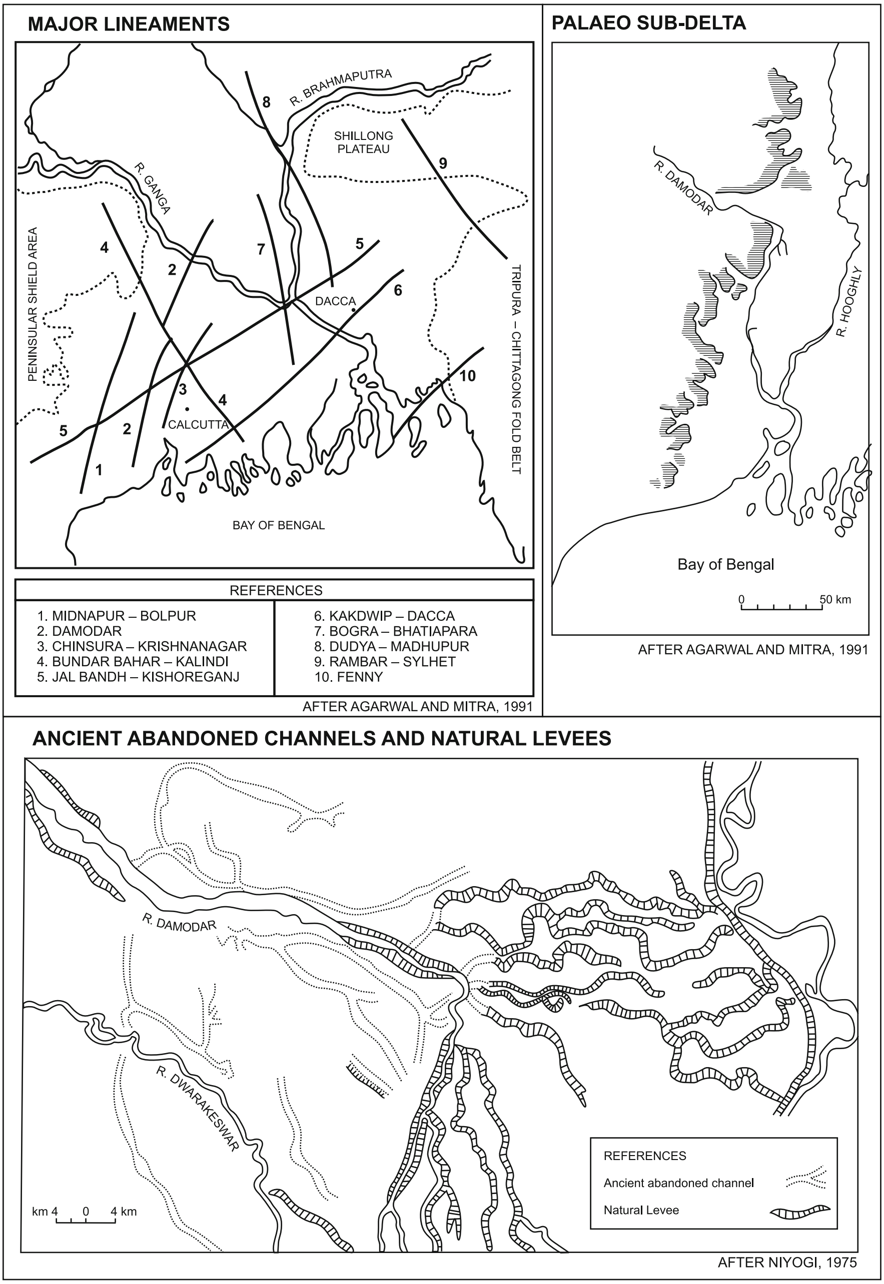

Fig. 6.33 Some Geomorphological aspects (a) Major lineament, (b) Ancient abandoned Channels and Natural levees, (c) Palaeo sub-delta. Source: 6.33 a, c. After Agarwal and Mitra 1991; 6.33b. After Niyogi 1978

absence of prominent mid-channel alluvial bars, a significant feature above Barsul-Chanchai. Treatment of the Lower Damodar below Barsul-Chanchai is separated not only on the basis of geological and geomorphological characteristics but also on the basis of settlement characteristics. This is the section where riverbed occupiers are not refugees.

6.8 Land Use Planning: Barsul Chanchai to Paikpara Settlement

Paikpara is a very old settlement in the Barddhaman district. It was previously known as Panchpara. In Bengali "panch" means five and para means locality. From the name Panchpara it appears that the settlement probably consisted of five localities. Paikpara is sited at the bifurcation point of the Muchi khal (hana) and the Damodar (Fig. 3.8). It is under the police station of Jamalpur of the Barddhaman district. The nearest railway station is Memari.

Paikpara is an oval-shaped village. The maximum length and width are 1.6 and 0.96 km respectively. The surface material is sandy loam. Initially, Paikpara (previously Panchpara) was sited on the right side of the river Damodar and the present site was shown as a point bar as is observed from Dickens's map of 1854. This map does not show any spill channel (Fig. 3.8). In the mid-nineteenth century, the right bank of the Damodar was almost open due to the removal of 32.19 km of the old embankments. But as has been mentioned previously, the left side was completely chained by high continuous embankments. This section has become very significant from a socio-economic point of view. Opening of spill channels or flood channels is a natural process at the delta stage of any low-gradient alluvial channel. In all probability, the Muchi hana was formed as a natural spill channel below Jamalpur. It is also possible that the removal of the right bank embankment helped in opening up spill channels. Such spill channels often develop as a consequence of neck cut-off. The Muchi hana has been referred to as Muchi *Khal* in the cadastral map of Paikpara. The term Khal is often used for an artificially cut channel. The local residents believe that the Muchi hana is a human-made channel. Such artificial cuts are common in the Mississippi below the Arkansas River. Schumm (1977) has referred to the dramatic shortening of the Mississippi River after 1929 as a result of artificial cuts-off. Thus, by 1856, the Muchi hana was a well-defined flood channel. In the map of 1957 the Muchi hana is shown as a wide braided channel. If 1,416 m^3/s of water passed through Rhondia in 1957, the entire discharge of the Damodar used to flow through the Muchi hana. At higher flood stages, a part of the discharge, though small, went into the Amta Channel (DVC 1957, V-I & V-II; Bhattacharyya 1998, 1999–2000a).

Regarding the opening of the Begua hana, the DVC report of 1957 mentions that a transverse dyke was put up across the Muchi hana in order to revive the old Damodar channel and to close the Muchi hana (DVC 1957, V-I). This measure, however, proved ineffective, helping, instead, to open the Begua hana (DVC 1957, V-I).

The general opinion is that that the opening of Begua hana is anthropogenic and the main purpose behind digging the Begua Muchi channel was to lessen pressure on the main Damodar and to save the settlements and the railway line on the left from flood havoc. The Muchi Begua is known as the Kanki further down and as the Mundeswari when it enters the district of Hooghly. The Begua channel was so narrow that it used to look like a village *nala* (brooklet) but within 20 years it has become a wide river. It is also believed that because of the widening of the Begua, flood propensity in an otherwise flood free area has increased. In the month of August 1993, extensive areas were flooded here (Bhattacharyya 1999–2000a). Paikpara is now bounded by the Muchi hana on the right side and the old decayed Damodar on the left. At the point where Muchi hana bifurcates, a high sand bank completely shuts off the flow of water into the Damodar and the newly scoured bed of the Muchi hana becomes lower than the sand-filled bed of the Damodar (Bose 1948; DVC 1957, V-I). As a result, the maximum discharge, i.e., more than 80% flows through this hana (DVC 1995). Paikpara now looks like a mid-channel bar (Fig. 3.8).

Paikpara is settled by local Bengalis. They are more or less undifferentiated in terms of religion, caste and occupation. The area between the Muchi hana on the right side and the old Damodar on the left is a region of continuous bank erosion and depopulation. In 1961 the total population of this area was approximately 811 and the total number of household was 115. This has been decreasing due to excessive bank erosion, especially on the left side of the Muchi hana. In 1971 the total population of this area was 455. In 1981 the total population decreased to 418 and the number of houses was only 65 (Census 1961, 1981). The population is still on the decline (Bhattacharyya 1999–2000a). In 2002 there were about 50 houses and the total population fell to 383.

Hydro-geomorphological characteristics strongly influence riverbed land utilization in Paikpara. Because of decreased flow, the Damodar riverbed, barring a few months in monsoon, looks like a string of stagnant pools. Within these stagnant pools, clay particles are deposited due to very slow vertical accretion and the low settling velocity of clay particles (Morisawa 1968). Clay-rich soil is mixed with sandy soil in order to increase water retention. The sandy bed load is thus put to agricultural use and water from stagnant pools is used for irrigation.

Crops grown in the Paikpara area are rice, potato, and oilseeds. Clay deposits on the riverbed are used for cultivation of wet rice. Arum is another important vegetable grown in Paikpara. Another noticeable feature of riverbed land utilization here is the cultivation of gamma grasses in order to arrest flood propensity. During monsoon, or if there is a back rush from the Muchi-Begua hana, the old Damodar looks like a perennial river. Water is then lifted from the river to irrigate the interstream areas.

There is a sand quarry on the Muchi hana near Fetehpur. The Bishalakshi dah i.e., natural lake or depression, on the Muchi hana is shown in the map surveyed in the year 1929–1930 (Fig. 3.8). Such depressions, locally known as "daha" are usually formed during floods due to scouring action of the water. Successive floods deepen these depressions which ultimately become components of the landscape. This depression was probably created during the floods of 1913. In the course of time this depression was filled up by sands as is observed from the SOI map of 1970. What was once a flow resource has now become a fund resource that is utilized for sand quarrying. Incidentally, it may be mentioned that at Similagarh and Pandua near Barddhaman, paleo channels of the Damodar were discovered by chance (Mallick and Bagchi 1975; Fig. 6.33c) and fertile agricultural lands were either sold or leased out for sand quarrying. Due to gradual deterioration of the physical and social environment, the Government of West Bengal has put a ban on quarrying activities since 1980 but sand heaps are still visible in that area. The sand quarries of Paikpara are owned privately, though revenues are collected by the government. Coarse sand is found below 0.91 m up to 1.2 m and is sold at Rs. 2,000 (1 US dollars = 45 Rs.) for every truck. Fine sand is sold at Rs. 225 for each truckfull. The trucks carry the sands to Calcutta. Price behavior of different types of sands indicates that sands are no more only fundamental entities but also important geomorphic resources and resource potentialities that have been enhanced, due to the nearness to Kolkata, where demand for sand is high for obvious reasons.

Fishing was also once an occupation of the people of this village. Some stagnant pools in the decaying drying main Damodar used to be utilized as fish ponds. Obstruction through minor control structures, however, has significantly reduced the fish population. Paikpara is approachable from the Jamalpur side. Cycles, rickshaws, and van rickshaws ply on the left bank embankment. During dry months the Damodar is fordable. During the monsoon it is navigable. The Begua-Muchi hana is navigable throughout the year and a bamboo bridge is found on the old Damodar.

Paikpara shares one of its characteristics with Gangtikali, the first settled bar below the Panchet reservoir. In Gangtikali there was a change in settlement site with the change in resource base from coal mining to agriculture. Change in the settlement site in Paikpara is due to truncation of an agricultural resource base on the one hand and emergence of a new resource base on the other (Fig. 6.34). Before the opening of the Begua-Muchi hana, the Paikpara settlement was on the left, away from the Damodar. But the old settlement site became vulnerable due to problems of bank erosion on the “hanas” and the settlement shifted towards the east where resource potentialities of the riverbed have increased (Fig. 3.8). This type of migration from west to east is thus partly ecological and partly impelled (Spencer and Thomas 1969; Bhattacharyya 1998, 1999–2000a). The people at least had some choice regarding when to migrate and where to migrate. Unlike refugees, the locals are more mobile on the social space.

Paikpara is still not free from flood havoc, as the cadastral map shows in the transverse alignment of plots. The far away Durgapur barrage also exerts its influence on the present settlement site. If discharge from the barrage exceeds 2,832 m^3/s, the area gets flooded. As a result, depopulation has become a common characteristic in Paikpara and the financially strong locals have no difficulty purchasing land outside the area.

Paikpara attained the status of a mid-channel bar due to opening of the Muchi-Begua hanas. Similarly, a few other overbank settlements became riverbed settlements due to construction of the left-bank embankment. Harogobindapur is one of

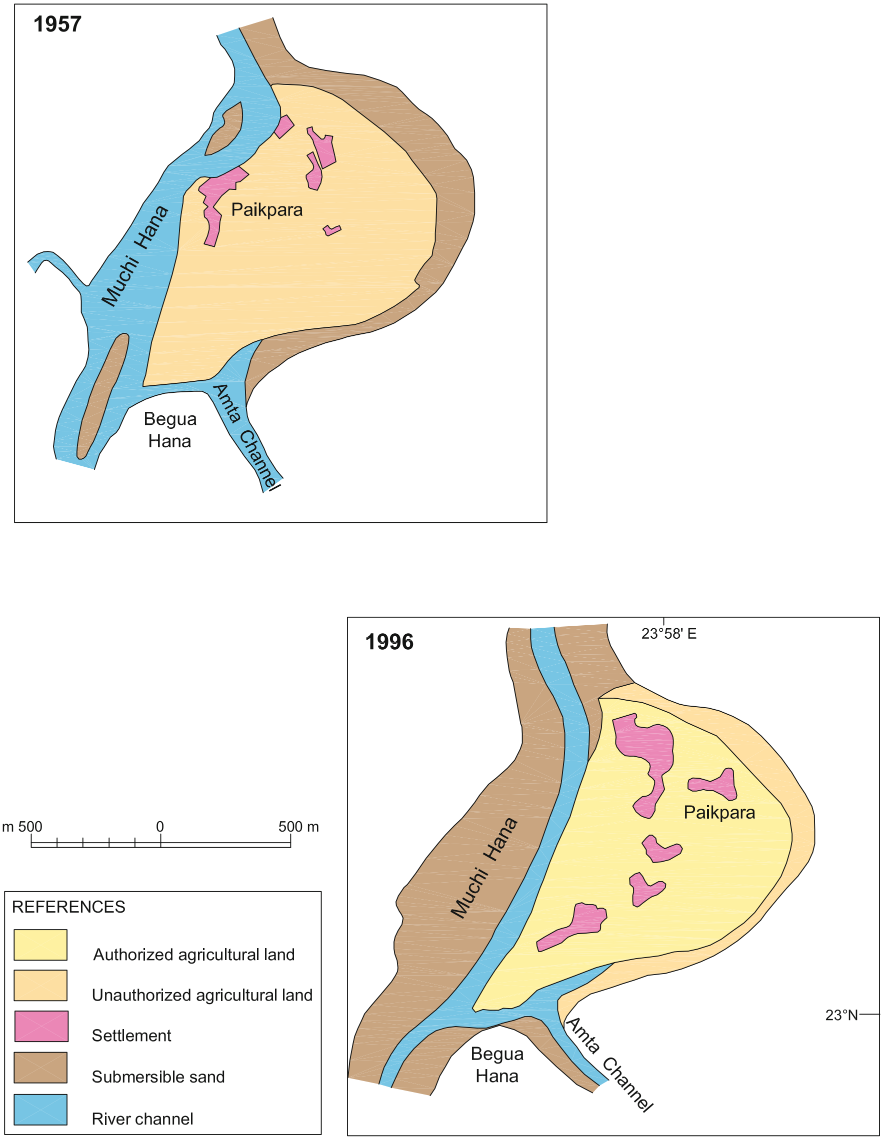

Fig. 6.34 Changes in cultural landscape of Paikpara
Map prepared from Paikpara mouza, 2003 LISS-3 scenes of IRS-ID satellite and field survey

them, protected by embankments on the left and the decaying drying Damodar on the right (Fig. 3.8). The main crops here are wet rice and potato. Despite protection provided by the left bank embankment, the agricultural landscape is less diversified in Harogobindapur. The embankments are lined with energy plantations and they form an important resource base for the riverbed occupiers.

6.9 Changing Resource Status from Flow Resource to Fund Resource

Paikpara is an example of changing of the location of a resource base subsequent to a geomorphic threshold. A neck cut off, known as Muchi hana, is the threshold which has brought about a series of changes. The opening of the Muchi-Begua hana has transformed an overbank settlement into a mid-channel settlement. What was once a part of the mainland is now a part of the riverbed. Here the Damodar bed has changed its resource status from a flow resource to a fund resource. The main Damodar has nearly dried up and now looks like a chain of stagnant pools. The Begua Hana has assumed the dimensions of a river and causes floods in flood years. The interstream area between the Damodar and the Muchi Hana is prone to bank erosion from both sides. Sudden release of water from the upstream barrage and reservoirs has increased bank erosion problems. Paikpara was safer on the western side, but now the western side has become hazardous due to bank erosion which has led to depopulation.

Compared to the refugee settlements above Barsul-Chanchai, Paikpara, settled by local residents, is less prosperous. Harogobindapur, like Paikpara, was also an overbank settlement but is now a riverbed settlement because of the left bank embankment. The settlement is shifting towards the east since the embankment is considered to be a safer location. The riverbed in this area is used for raising cereals, vegetables and oil seeds. Gamma grasses are grown in flood-prone parts of the bed. Excess water from the old Damodar is pumped out and used for irrigation. Riverbed sands are quarried to be transported to Calcutta. Strip plantations on the embankment form an important resource base.

6.10 River Bed Characteristics: The Amta Channel

Below Paikpara, the controlled Lower Damodar takes a new name, the “Amta Channel” (Fig. 2.1). As the main flow (more than 80%) passes through the Mundeswari (DVC 1995; Bhattacharyya 2002), the Amta Channel looks like a rivulet chained with embankments. The width of the channel never exceeds 1 km. The channel is conspicuous by an absence of mid-channel bars, a significant and important within-channel feature in the upper sector of the Lower Damodar. Bars in the Amta Channel are longitudinally-oriented narrow marginal bars.

The stretch between Paikpara and Bahir-Aima, the farthest settlement near Falta outfall, includes 170 mouzas and comes under the police stations of Jamalpur of the Barddhaman district and Dhaniakhali, Tarakeswar, Jangipara and Pursura of the Hooghly district and Udaynarayanpur, Amta, Bagnan, Uluberia and Shampur police stations of the Howrah district. The nearest railway station and town is Uluberia.

The total length of the Amta channel is 107 km. The thalweg of the Amta channel is extremely narrow compared to that of the Kanki-Mundeswari. Hydraulic sinuosity index of this Amta channel is 5.71 and topographic sinuosity index is

94.29. The river is shallow and fordable at many places. There are embankments on both sides; the right bank embankment is closer to the river. Between Habibpur Chaitanyabati there are double embankments. At Chaitanyabati and Nachhipur, the main left bank embankment is 1.5 km away from the river, indicating the flood propensity of this side. Heights of the embankments vary from 4 to 5 m. The lower part of the Amta channel is affected by tides but the tidal influence has been restricted due to the Ulughata sluice. The Amta channel can be divided into two sectors. Sector-I extends from the Kanki-Amta bifurcation point to the Ulughata sluice and Sector-II extends from the Ulughata sluice to the Falta outfall. Below the Ulughata sluice, the Amta channel has almost become a defunct channel (Fig. 2.1, Plate 6.14). The natural Amta channel is very narrow but the riverbed within embankments is very wide in many places as has been mentioned above. There are few settlement sites in this riverbed. These settlements are extensions of the mainland settlements. Residents are locals with Hindus dominating. The Amta riverbed is devoid of refugee settlements. The most important settlement is the Bahir Aima.

6.11 General Land Use in the Amta Channel

The main food crop in the riverbed is wet rice, while the main cash crop is potato. Other crops are extensively grown with the help of well and tube well irrigation, but tube well irrigation is restricted to a very few settlements such as Kumral, Nachhipur and Mirzapur. At Habibpur and Chaittanyabati, tank irrigation facilities are available.

Marginal bars from Diwantala to Chhayani Gujrat under Bagnan police station of the Howrah district are used for floriculture. Two types of flower trees are selected, perennial and seasonal. Rose (*Rosa centifolia*) and Hibiscus (*Hibiscus rosa-sinensis*) belong to the perennial group whereas marigold (*Tagetes patula*), chrysanthemum, and cosmos are seasonally cultivated. Here, land elevation, soil texture, and structure, albeit important, are less significant than economic factors. Flowers are a perishable commodity and therefore require a rapid transit system. Proximity to the Jagannathghat, the biggest flower market in eastern India (near the Howrah station), and railways, are the main economic factors behind selection of floriculture in these marginal bars. Selection of rose, hibiscus, and marigold, however, has a socio-cultural significance. Apart from ornamental value, rose, hibiscus and marigold have religious, cosmetic and therapeutic value. Roses are used during Hindu religious ceremonies, and are a sacred flower to Muslims; incidentally the nearby villages have a sizable Muslim population. Rose water is supposed to have therapeutic value. Perfumes are also manufactured from rose. Hibiscus is the most sacred flower among a section of Hindus known as Shaktas who worship the goddess Kali. As a result, there is a great demand for this flower during Dipavali (the biggest festival of India) in the month of October when goddess Kali is worshipped in West Bengal. There is a perennial demand for this flower wherever Kali temples exist. Hibiscus and its leaves are coveted items in the herbal cosmetic industry.

This industry manufactures herbal oil from hibiscus. Bright coloured marigolds have an extensive market during marriage ceremonies of all religions. Marigolds are also required for worshipping Saraswati, the goddess of learning. In the month of February almost all educational institutions observe this festival of worshipping Saraswati. Finally, cosmos and crysanthemum are used for decorative purposes. These economic and social factors – namely, connectivity and market demand – have played a decisive role in the selection of such perishable crops such as flowers in these riverine bars (Bhattacharyya 1998).

Some of the marginal bars along the Amta channel from Diwantala to Ranibhog are noted for making tiles and bricks (Plate 6.15a, 6.15b). Salt-free sandy soil is good for tile manufacturing. The sandy loam soil is mixed with clay soil collected from the surrounding area and is used for making tiles; the period in which this generally occurs is from November to April i.e., in the non-monsoon months. There are a significant number of tile factories in this bar. This sandy loam soil mixed with clay soil is also suitable for making bricks. There are many brick kilns from Diwantala to Ranibhog. The demand for tiles and bricks has increased in urban as well as in rural areas.

Marginal sandbars from Boalia to Garh Chumbak just above Diwantala near Ulughata sluice are used mainly for betel leaf plantations (Plate 6.16, 6.17). Betel leaf plantations last long in clay soil and betel leaves of superior quality are usually grown in clay soil. Here, however, betel leaf plantations are a significant component of land use in the sandy loam soil along the Amta channel. Like floriculture, the size of a betel leaf plantation is also fostered by economic feasibility. There is a demand for betel leaves among Bengalis and proximity to the Kolkata provides a ready market for this perishable commodity.

If we make an observation on the generalized land use characteristics in the marginal bars of the Lower Damodar i.e., in the Amta channel, we notice that vegetables such as potatoes are grown extensively on the marginal sandbars of the Hooghly and Howrah district. In the marginal sandbars of the Howrah district, long melon (*C. Melo Var, Utilissimus*), watermelon (*Citrullus vulgaris*) and cucumber (*cucumis sativas*) are also grown. General land use characteristics of a part of the Amta channel have been shown (Fig. 6.35). Due to drainage diversion by the Ulughata sluice, the flow resource below the control point has lost its significance. Instead, the exposed riverbed is used as a renewable fund resource. Two cross sections have been selected for display from the moribund Amta channel (Fig. 6.36).

Section-1 shows cultivated lands between the base of the left bank embankment and the thalweg. The area between the right bank embankment and thalweg is cultivated. The land adjacent to the thalweg is divided into several plots by earthern dykes. Water is collected in the area enclosed by dykes and wet rice is cultivated. A prawn-fish project was proposed but the proposal was dropped due to protests from environmentalists. Vegetables are grown together with paddy. The area below the right embankment is used for homesteads.

Section-2 shows similar features of land use. The only difference is that there are betel leaf plantations near the left bank embankment and tile factories near the

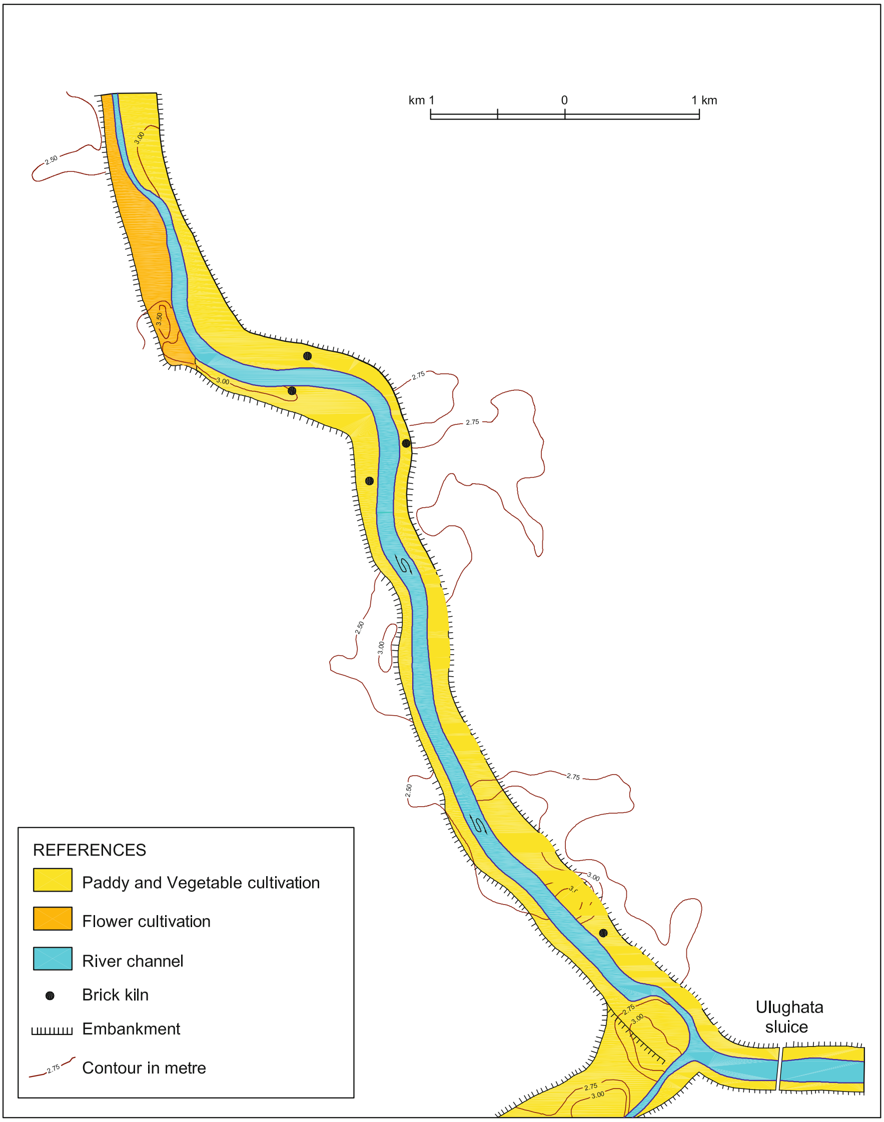

Fig. 6.35 Generalized land use characteristics of a part of Amta channel
Map prepared from 1: 15,000 79 B/13/2 and through active field survey

right bank embankment. The ditch just below the right embankment now contains a *hogla* jungle (a kind of tall grass). It is noteworthy that the betel leaf plantations are sited on the higher part of the riverbed, as are the tile factories (Bhattacharyya 1998).

The marginal bars mentioned so far are not settled in general. A few hamlets are to be found on the right side. The biggest settlement is the Bahir Aima (Fig. 2.6).

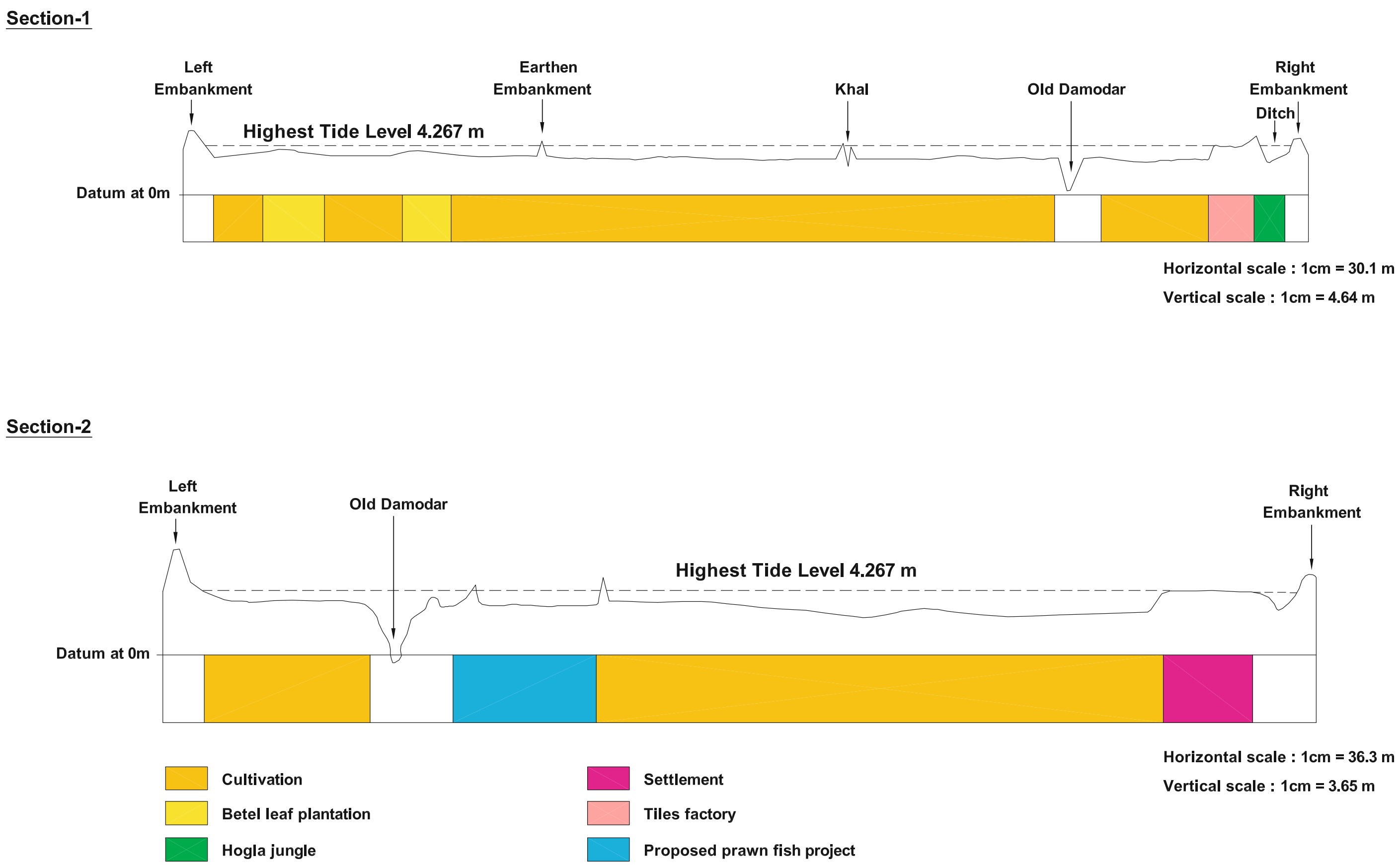

Fig. 6.36 Cross sections showing interrelationship between physical and cultural landscape at defunct section of the Amta channel
This Figure prepared from cross sections collected from I & WD, WB and through active field survey

6.11.1 Bahir Aima

Bahir Aima is the farthest settlement on the Lower Damodar from the Panchet and Maithon reservoir. The distance between Gangtikuli, the first settled bar just below the Maithon and Panchet reservoirs, and Bahir Aima at the Falta outfall, is approximately 250 km. This settlement is an extension of the Alipur settlement. Bahir means outside and Aima denotes settlement. Bahir Aima is sited on a marginal bar in the Hooghly estuary. It comes under the mouza Alipur under the Srirampur police station of the Howrah district. It is sited at a previous confluence point of the Damodar with the Hooghly. The nearest railway station is Bagnan.

Bar formation in any estuary is a part of an estuarine process. Due to the mixing of salt water with freshwater, flocculation takes place and there is rapid sedimentation leading to bar formation. The Bahir Aima bar was probably a product of this process at the initial stage. We noted earlier that the Amta channel started deteriorating after 1865. The construction of the Durgapur barrage and the Panchet and Maithon reservoirs has further reduced the amount of stream discharge since 1958 and finally, due to the construction of the Ulughata sluice, the lowermost part of the Lower Damodar has deteriorated further. As a consequence, a sluggish environment was created at the Falta outfall that was conducive to the formation and enlargement of bars. The construction of embankments in 1956 led to vertical and lateral accretion, thus enlarging the Bahir Aima bar. Near Bahir Aima, the Amta channel is so narrow that it looks like a village nala (Plate 6.16) but ruined dilapidated bacon still bears the evidence of the past glory of the Falta outfall.

The Bahir Aima is dominated by Muslims who migrated to this bar after 1958. There is a floating population from Alipur. They have land in Bahir Aima but are not settled there. Settlements are on the landward side of the bar. Cultivated fields extend right up to the riverfront. In fact, the riverfront is preferred due to fortnightly replenishment of soil fertility by tides in an otherwise moribund situation. In the British period, salt used to be manufactured from saline water intrusion but now this activity is not significant. Wet rice and vegetables are grown here but there is a lack of crop diversity in general. The bar is so stable that coconut and palmyra trees have been planted everywhere (Bhattacharyya 1998).

6.12 Summary of Land Use in the Amta Channel

The thalweg of the Amta is extremely narrow compared with the culturally defined riverbed. Embankments have been constructed at equal distances from the natural river. The right bank embankment is comparatively closer to the river whereas the left bank embankment has been constructed quite a distance away from the main river at many places. The embankments are rather evenly spaced in the lower part of this section. Configuration of the culturally defined riverbed varies between almost level surfaces to slightly undulating surfaces. Riverbed occupiers are mostly local residents. Among locals, Hindus dominate, though there are a few Muslim families.

Almost the entire bed is used for cultivation. Crops vary from paddy to potato. Transverse dykes have been constructed on the riverbed for paddy culture resembling basin irrigation of ancient Egypt. There is an extensive floriculture in some of the inundation-free marginal bars. Proximity to the Jagannath ghat flower market and connectivity to this market by roads and railways have encouraged floriculture, a striking land use characteristic of the controlled riverbed of the Amta channel. Economic factors have helped in creating betel leaf plantations on higher parts of the riverbed. Tile factories and brick kilns are observed on the highest part of the inundation-free riverbed. Hogla forests are found in marshy areas of the riverbed. A proposal for prawn culture was dropped due to protests from environmentalists. The natural levee is almost lined up with the settlements in a few places. Embankments are used as village roads.

The flow resource is losing its significance, particularly below the Ulughata sluice, but marginal sandbars are extensively used. The emphasis on perishable but expensive crops like flowers and betel leaves is noteworthy. This risk has been taken because of market facilities available in nearby Howrah and Calcutta and due to easy market access by road and railway. Urban markets in the vicinity have also made tile factories and brick kilns significant components of the cultural landscape. These components are not so significant in other two sectors of the Lower Damodar (Bhattacharyya 1998).

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Chapter 7
The Controlled Lower Damodar River: A Product of Hydro-Geomorphic and Anthropogenic Processes

Abstract The Lower Damodar should be culturally defined. Forms, processes and materials in the controlled section are generically quasi-natural in character. Social space of Bengali refugees has played a significant role in riverbed colonization and in subsequent land use practices. There is a strong linkage between changing geomorphic space and perceived environment. Land ownership rights are crucial factors in riverbed land utilization. The modified concept of human ecology helps in explaining land uses. There can be no a priori model for human-environment interactions. Human interaction with the environment depends on personal experience. The controlled Lower Damodar is a product of twin processes; quasi-natural hydro-geomorphic processes on the one hand and anthropogenic land-utilization processes on the other.

Keywords Anthropogenic · Flood · Flood control measures · Human ecology · Human-environment interactions · Hydro-geomorphic · Land use · Social space

7.1 The Lower Damodar, a Product of Human Activity

In the preceding chapters applied geomorphological issues, ranging from floods, flood control measures and their impacts on selected hydro-geomorphological parameters to river-bed land use in the Lower Damodar River, were discussed in separate sections. The purpose of this segmented discussion was to highlight individual issues. In Chapter 2 several concepts were discussed as heuristic assumptions. Now, these segmented issues must be unified and the validity of heuristic assumptions established.

Our first assertion is that the Lower Damodar, as it is today, is clearly a product of human activity. The natural east-west trend of the river, southward deflection below Barsul-Chanchai, and the deferred junction with the Hooghly, are conditioned by regional slope and sub-surface lineaments. The riverbank was the natural boundary of the river and its flood propensity was inherited from hydromorphological and meteorological conditions prevailing in the entire Damodar basin. The Lower

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Damodar River used to adjust with excess discharge through a well-defined distributary system on the left and spill channels, or hanas, on the right, failing which extensive areas in the present Barddhaman, Hooghly, and Howrah districts used to be flooded. It started losing its identity as a natural river in the later half of the eighteenth century due to human intervention in the form of embankments. The near gradation of the river was disturbed in different phases by artificial base levels created by the Jujuti sluice, the Rhondia weir, the Durgapur Barrage, the Panchet and Maithon reservoirs, and finally, by the Ulughata sluice. Since the completion of the Maithon and Panchet reservoirs, the river has been transformed into a "reservoir channel" or a "reserved controlled channel". The Lower Damodar is now identified by control structures, cultural features, and human made indicators.

7.2 Forms, Processes, and Materials in Controlled Section Are Quasi-Natural in Character

From the notion that the Lower Damodar needs to be culturally defined has emerged the second assertion of this research: that forms, processes and materials in the controlled sector are quasi-natural in character because of human intervention with the natural fluvial system by means of control structures. It is not to be denied that the emergence, migration, and stabilization of bars are products of fluvial processes, but stabilization of bars has become more significant due to sediment trapping by roots of cultivated vegetation. Even the inundation-prone peripheral zones of settled bars do not remain fallow. Either grasses are grown or crops of low value and quick-maturing crops are grown as additional crops in bars such as Bara Mana and Kasba Mana. Decaying channels with clay deposits are also used for wet rice at Ramkrishnapalli, Pallishri, Bara Mana, Rangamatia, and Fatehpur (Bhattacharyya 1998, 1999, 2008b). In Paikpara, the bed of the Damodar is intensively cultivated in the non-monsoon period. Furthermore, domesticated vegetation and the addition of artificial fertilizers have changed the very composition of the soil. All these cultural practices have helped in stabilization and extension of riverine bars and in developing human-induced modified soil profiles (Bhattacharyya 1998).

The above statements do not necessarily imply that the stabilization of bars and changing soil composition due to land use practices should be interpreted as anthropogenic processes. Man may be a geologic agent, a concept supported by Sherlock (1922), Thomas (1956), Brown (1970), and others. Although the role of humans as geologic agents in shaping the earth's surface depends on the level of technological expertise, sedimentation and pedogenic processes are governed by universal physical laws. In contrast, land utilization, an anthropogenic process, is governed in the truest sense by location-specific socio-cultural and politico-economic factors. Comparing observations and assessments from several case studies on the river-bed land utilization in the Lower Damodar, we can justifiably conclude that simultaneous operation of fluvial and pedogenic processes on the one hand and anthropogenic processes in form of land utilization on the other have resulted in forms, processes and materials in the Lower Damodar that are "quasi–natural" in character. This claim was introduced in Chapter 4 while examining the hydromorphological consequences of control structures and was again re-examined while assessing river-bed land utilization. To differentiate it from a physical environment where everything is natural, it is proposed that, for a historical environment, the term “quasi-natural” be adopted as an adjective for geomorphic forms, processes and materials (Bhattacharyya 1998).

7.3 Concept of Culture in Resource Appraisal

In the analysis of riverbed land use and settlements, less emphasis was placed on origin and more on adjustment patterns in a physical and socio-cultural milieu. The riverbed was assumed to be a resource base and not a resource in itself. In the sections of the river studied, potential resources of the riverbed are fairly uniform. Sandy loam, for example, is found almost everywhere. Use of these undifferentiated bed-materials, however, has been spatially and temporarily differentiated based on the cultural proclivities of the settlers. The riverbed users are mostly Bangladeshi refugees but there are a few families of Biharis in places like Gangtikali and Gaitanpur. Since Bengalis are rice eaters, paddy is the main crop in Bengali-dominated settlements, whereas wheat is the crop of choice in sand bars dominated by the Biharis who primarily eat a type of bread. Bangladeshi refugees have introduced jute as a cash crop as they were used to jute culture in their previous habitat in Bangladesh whereas potato culture was introduced in Rangamatia, Fatehpur and Kasba Mana by locals who migrated from the Hooghly district, noted for potato cultivation, after the 1978 floods. Imprints of acquired local culture are evident in Bara Mana and Majher Mana where mulberry plantations have become significant components of the cultural landscape after 1978. The linkage between mulberry plantations and the silk culture of Bankura-Bishnupur does not require any further explanation. Floriculture in Bara Mana, Gaitanpur as well as in Chhayani Gujrat and Panchani Gujrat is no doubt governed by strong economic factors i.e., market facilities in Durgapur, Barddhaman and Howrah but selection of flowers such as marigold, hibiscus and rose is motivated by religious demand. Betel leaf chewing is a widely prevalent habit in India. Apart from market facilities in Howrah, this national cultural trait has played a decisive role in the growth of betel leaf plantations in the river-bed of the Amta channel (Bhattacharyya 1998). Admission of the concept of culture in resource appraisal is not new in applied geomorphological or human environmental research. This concept is used here to explain functional relations between the riverbed resource base and its users.

7.4 Significance of Social Space in Colonization Processes and Land Use Practices

Apart from cultural variations and preferences, the other major social/psychological factor influencing riverbed land use is the fact that most of the Bengali settlers are refugees, a status with legal, social and economic connotations (Kuper and Kuper

1995). In the Lower Damodar riverbed, they are not majority-identified refugees, but self-alienated refugees. This very definition and status have played a crucial role in sequential occupation of the riverbed by refugees and in land utilization. It is a global experience that refugees are not fully accepted by host communities, particularly when the same economic sector has to be shared. The riverbed occupiers were from the farm sector in erstwhile East Pakistan or present Bangladesh, a sector already saturated in West Bengal when millions of Bengalis crossed the border. So, from the very beginning, host communities perceived these migrants as parasites. The refugees themselves were keenly aware of their outsider status. The newcomers were not differentiated from the Bengalis of West Bengal in terms of language spoken or religion. In fact, prior to partition, their social structure and organization was conditioned by similar ecological and cultural factors. But their newly acquired refugee status created a distance from the locals. This distance was a perceived distance. Although they were forced to share the same physical space or geometric space in West Bengal, their position in the sociological space was different. This perceived space is the social space as advocated by Durkheim in 1933 and also by Sorokin (1928, 1959), Theodorson and Theodorson (1969), Chombert de Lauwe (1952, 1956), Buttimer (1969, 1980) and Bhattacharyya (1998, 1999, 2009). A section of the refugees' deserted government-sponsored colonies and camps. Thus from "majority-identified refugees," they became "self-alienated refugees." At this juncture the riverbeds of West Bengal became their new addresses or "niche." In the Lower Damodar sand bars, locations with disadvantages were selected so that their self-alienation could be retained and they could avoid resistance from the locals. In the plantation history of the world it has always been observed that newly arrived groups at the initial stage try to avoid clashes with locals and start plantations in terrains perceived as less fertile by locals. Examples of this phenomenon include the rubber plantations in Malaysia as well as tea and coffee plantations in India and Sri Lanka. This is a common feature of the colonization process. So when the barren sand bars with grass jungles, away from main transport routes, were occupied by refugees, the locals did not raise any protest because to them the sand bars were just fundamental entities.

Colonizing ab initio in a totally different environment, the refugees in the Lower Damodar riverbed assessed the controlled riverbed not as it was but as it was perceived by them, a perception conditioned by their felt position in society, i.e. social space. Since their social mobility was restricted, they adopted a "self-help" policy. They cleared the jungles and built their own huts. To reach a minimum level of self-support in food production, they started growing essential food crops. Apart from paddy, an inferior species of bottlegourd (*Legenaria Siceraria*) locally known as "khero" was introduced in fresh sands of low nutrient status. The falling of leaves and animal droppings enhanced the fertility of sandbars. In later stages they tried to sell part of their crops grown for additional income to attain a level of self-reliance (Bhattacharyya 1999–2000b, 2008b). The granting of land deeds to the refugees has given them a further measure of self-sufficiency and parity with the locals. This is the experience in almost all refugee-settled sandbars. Rogge (1987) has observed these sequential changes in refugee settlements in Sudan but has not used the term "social space." Verstappen is eloquent about socio-economic controls on rural land use (Verstappen 1983). Applying these ideas in the context of the Lower Damodar, it can be stated that one's perceived position in society, perceived relations with others, and perceived social distance or mobility are *sine qua non* in developing a functional relation with a given resource base (Bhattacharyya 1998).

7.5 Strong Linkages Between Changing Geomorphic Space and Perceived Environment

A question that naturally arises from the previous discussion is the following: is there any relationship between changes in perceived environment and changes in real environment? Craik (1970), Clayton (1971), Cooke and Doornkamp (1974, 1990), Basu (1988), Verstappen (1983), Hart (1991), Bhattacharyya (1998, 2009), and Gregory (2006) realized the need for applying perception concepts in applied geomorphological research but there is a lack of empirical study in this area. Saarinen (1966), Correia et al. (1998), Bhattacharyya (1991, 1997, 1998), Ladson and Tilleard (1999), Darby and Thorne (2000); Downs and Gregory (2004), Piegay et al. (2005), Chin and Gregory (2005), and Gregory (2006) in research on hazard, river management and on humans' role in changing fluvial regime have emphasized the concept of perception and perceived environment.

In this study of the Lower Damodar, the concept of perceived environment in examining the functional relations between the riverbed and its occupiers is utilized. Changes in real environment are recorded on the geographic space. Different types of control structures, changing boundaries of sand bars, the opening of spill channels, the deterioration of distributaries, and other similar changes leave their cognizable imprints on the surface. Perceived environment is reflected in land use practices as it is shown below through the examples of Gangtikali, Paikpara and other parts of the Damodar riverbed. Just as there is an overt expression of social space, the perceived environment has its overt expression through selection of settlement sites, crops to be grown, and so on.

In Gangtikali, there was a change in real environment when coal mines on the west were flooded in 1959. Prior to this event, the islanders did not perceive the agricultural resource potential of the east side. In fact, their interaction with their environment had been essentially dictated by the coal mining company which saw Gangtikali only as a geological resource. After the 1959 floods, however, the islanders, driven by the need to look beyond coal mining, began to realize the agricultural resource potential of the eastern part of the island. The settlement sites shifted from west to east (Fig. 6.1). Since Gangtikali is located at a higher elevation, release of water from the reservoirs turned out to be a boon for lift irrigation.

There were a series of changes in geomorphic space and geomorphic resources in Paikpara with the opening of the Muchi-Begua hanas and the Kanki-Mundeswari. The main flow of the Damodar shifted to the Kanki-Mundeswari and the old Damodar deteriorated to such an extent that its bed became agricultural land during non-monsoon periods. The bed of the old Damodar is now perceived more as a fund resource and less as a flow resource. Moreover, people view the Muchi-Begua hana side as vulnerable due to bank erosion. In accordance with this there is an out-migration from Paikpara and the main settlement site is shifting towards the east (Fig. 6.23). Observable changes in real geomorphic environments have occurred below the Ulughata sluice. The Lower Amta channel has almost become a defunct channel and has been unofficially declared defunct by the executive engineer, Irrigation and Waterways Department, Government of West Bengal. Environ-sensitive betel leaf plantations are located here as the area is perceived to be safe for these plantations.

When the first group of settlers arrived in the riverine bars, the Durgapur barrage, Maithon, and Panchet reservoirs were yet to be constructed. There was a rapid change in real environment when these three emerged as major transverse control structures. Monsoon flow decreased, peak flow reduced, and there was a shift of peak flow from July–August to September (Figs. 4.2, 4.3, 4.6a, 4.6b, 4.7; Tables 3.3 and 4.5). There is no doubt that perceived environment constructed by the refugees changed just as rapidly. They quickly discerned the effect of the water release from the reservoirs and barrage and the inundation patterns of their land. All these examples indicate that perceived environment changes with changes in the real environment, though not always at an equal pace. Sometimes perceived environment changes faster than the changes to be observed in the real environment and vice versa. For instance, when refugees sought out remote and barren sandbars as desirable locations, their perception of the advantages of their environment were not conditioned by any actual changes to the real environment. On the other hand, the 1978 floods caused remarkable changes in the real environment, severely damaging several riverine bars. There was, however, no consequent change in the perceived environment of the refugees due to their restricted social mobility and economic constraints. It can be concluded, therefore, that there is a close link between changing geomorphic space and perceived environment, and that perceived environment is conditioned by social space (Bhattacharyya 1998).

7.6 Public Policy and Land Ownership Rights

A discussion of the factors that influence perceived environment would not be complete without touching on issues of law and public policy. A cardinal change in perceived environment has occurred after the refugees were granted land deeds. This legal step has given refugees a level of self-sufficiency beyond the level of self-help they attained in the initial stages. Environmental perception was embedded in the decision to build embankments on the flood-prone Lower Damodar, in removing the right bank embankment in places, and in constructing modern control structures. But execution or realization of decisions was made possible only by government policy. This is true, though not as much, for agricultural practices. After the partition of India in 1947, cultivation of jute in West Bengal was encouraged by the government as major jute-growing areas were in erstwhile East Pakistan (presently Bangladesh) and jute mills were in the Hooghly industrial belt. This illustrates the vital concept that legal issues, however sensitive they may be, need to be incorporated in applied geomorphological as well as human-environmental research. Geomorphological expertise can only be used to solve practical problems if it is supported by public policy. Pitty (1982) has drawn attention to the importance of public policy in the application of geomorphology in flood control measures while commenting on Hails's remark that most geomorphologists are interested in individual academic pursuits and not in solving practical problems (Hails 1977; Pitty 1982). Since colonization, refugees have struggled to fortify their forcibly occupied resource base in self-sought settlements. It is only after gaining land ownership rights have they begun to view the riverbed as their own. A kind of allegiance or topophilia has developed among refugees (Bhattacharyya 1999).

7.7 A Modified Concept of Human Ecology Helps to Explain Land Use

At a particular historical juncture, the riverbed of the Lower Damodar became the second habitat of Bangladeshi refugees and alluvial bars their new addresses/niches/micro-habitats. The functional relations that have developed between riverbeds and refugees exemplify the concept of human ecology as proposed by Park and Burgess in 1921 (Theodorson 1961). In the present study these concepts have been modified taking a socialistic view-point. Refugees have extended their resource base right up to the inundation-prone peripheral zones of sand bars by growing crops of low value as additional crops. Decaying channel beds have been used for paddy crops. In the bank erosion-prone areas they take immense care to grow grasses. Wherever horizontal extension of the existing resource base is not possible they use the land for multiple cropping, thus expanding the resource base vertically. Initially they were treated as parasites by host communities. That parasitic relationship has now been replaced by a relation of competitive cooperation and this relationship has evolved through interactions such as the exchange of commodities and extension of market facilities. The Bara Mana is a good example of all human ecological issues in an alluvial bar. From growing inferior crops in nutrient-poor fresh sands, they have gone through several serial stages in agriculture and now have almost reached a productive peak by growing plantation crops such as mulberry (Bhattacharyya 1999–2000b). This has been possible due to increased accessibility to markets and enhanced social and economic mobility of the community. A deviation from the classical position of human ecology is possible by resolving that survival potentialities of communities are not genetically transmitted but acquired through personal experience. The concept of "survival of the fittest" as proposed by Darwin and later followed by conventional human ecologists has been applied in this human-environmental research, but in this argument the “fittest” refers to technological fitness. Fitness is acquired cultural fitness as well. The people of Rangamatia are fighting against bank erosion by constructing a series of dykes (Bhattacharyya 1998, 1999, 2008b). Based on these observations, it can be asserted that the concept of human ecology in a modified form is clearly relevant to applied geomorphological and human-environmental research.

7.8 Human-Environment Interactions Depending on Personal Experience

The importance of personal experience in enhancing survival fitness ensues from the fact that the river-bed dwellers had no a priori model to guide them in their new habitat. Most of them come from deltaic Bangladesh where rivers are perennial, flood slope is gentle, speed of on set is slow and riverbed materials are clayey. In the former East Pakistan or in Bangladesh they were not used to living in a riverbed. Moreover, the rivers in Bangladesh have not yet become reservoir channels. Physical characteristics of the Damodar are different in terms of flood-slope, flood-speed and bed materials. Thus, the riverbed dwellers had no a priori model before them. Their decisions regarding selection or change of settlement sites have been conditioned by their personal experiences which have changed over time. Similarly, their personal experiences have helped in selecting crops from cereals to high-value cash crops. From personal experience, the riverbed users of Paikpara have come to know that the old Damodar is drying up and that the Muchi-Begua is posing a problem for them. So there is a flight of population in face of an anticipated calamity. In contrast, a mulberry plantation has been introduced in the refugee-dominated Bara Mana and Majher Mana. Riverbed dwellers have learned through experience that if water is released from the reservoirs, the highest part of the bar remains above inundation level. Western philosophers like Hume, Burkley, and Indian philosophers belonging to the school of Carvac have always advocated for empiricism or sense experience in explaining human behavior. Through personal experience, the islanders of Gangtikali have come to know that the release of water from the Panchet/Maithon reservoirs has no inundation risks for them, whereas in Damodar Char Mohana, release from the reservoirs and backrush from the barrage becomes hazardous. This stretch between Durgapur barrage and Majher Char has become safer for the settlers due to controlled flow from the reservoirs. The riverbed users know which parts of their settlements will be inundated and to what extent they will be inundated. Through personal experience they have learnt the hydromorphological consequences of several control structures and changes in overall socio-economic and political environments. Therefore, it is ultimately personal experience that has played a decisive role in developing a functional relation between the riverbed of the Lower Damodar and its users (Bhattacharyya 1998).

7.9 The Reservoired Lower Damodar, a Product of Hydro-Geomorphic and Anthropogenic Processes

The Lower Damodar shares many of its hydro-geomorphic characteristics with other controlled rivers in India and elsewhere. No other regulated river, however, has such a high density of riverbed population. Embankments, weirs, barrages and reservoirs have become familiar components of the landscape in the Lower Damodar. Similarly, settlements, agricultural fields, and rural roads are now viable elements of the riverbed between the Maithon and Panchet reservoirs and Falta outfall. The landscape that has emerged is thus quasi-natural and human-modified in character. In fact, almost all major rivers in the world are generically quasi-natural. The foregoing discussion on observations and explanation of floods, flood control measures, consequent changes in selected hydro-geomorphic phenomena, and land use practices in the Lower Damodar, leads us to several broad conclusions. It is clear that the controlled Lower Damodar should be culturally defined. Forms, processes and materials in the controlled section are generically quasi-natural in character. The social space of Bengali refugees has also played a significant role in colonization in the riverbed and in subsequent land use practices. There is a strong linkage between changing geomorphic space and perceived environment. Land ownership rights have turned out to be crucial factors in riverbed land utilization. Since no a priori model exists for river bed colonization, human-environment interaction under these conditions depends entirely on personal experience. A modified concept of human ecology has proved to be useful in explaining land use practices. The controlled Lower Damodar is a product of twin processes; quasi-natural hydro-geomorphic processes on the one hand and anthropogenic land-utilization process on the other.

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Chapter 8
Towards Better Human–Environment Interactions

Abstract The Damodar riverbed has provided a home for marginalized communities, but the riverine environment itself has deteriorated; presenting us with a challenge to develop a more holistic and sustainable water management system. There should be a mix of structural and non-structural measures that acknowledge and incorporate local cultural attitudes, experience and knowledge. For effective water resource management, river communities must be part of the effort so their interests are aligned with the aims of the project and they feel committed to the success of the endeavor. River regimes should be treated as economic assets since ongoing economic and human development depend on an ecologically sound riverine environment.

Keywords Cultural attitude · Ecologically sound · Holistic · Integrated water resource management · River community · River regime

8.1 Discussions and Suggestions

Human beings through millennia have impacted the fluvial environment, directly through engineering projects (Leopold et al. 1964; Agarwal and Narain 1997; Bhattacharyya 1998, 1999; Gregory 2006) and indirectly through changing land use and landscape (Nüsser 2001; Goudie 2006a, b; Wohl 2006; Wohl et al. 2009; Kondolf et al. 2007; Kummu and Sarkkula 2008; Richter et al. 2010). The natural resources of the planet are now controlled mostly by anthropogenic forces rather than natural forces (Turner et al. 1990; Misserli 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; Ehler 2008; Zalasiewicz et al. 2008).

The Damodar River has been controlled by government and riparian communities through the centuries using macro- and micro-level planning and river training programs. Embankments, canals, sluices, weirs, dykes, barrages, dams, and reservoirs are now integral components of a historically conditioned geomorphic

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landscape (Bhattacharyya 1998, 1999–2000a, 2008b). The Damodar River landscape therefore, like other major rivers of the world today, is ordinarily shaped by anthropogenic processes. Though geomorphologists are a bit skeptical that these alterations have "permanently altered the river dimensions. As we know from fluvial geomorphology, nothing is permanent – certainly not in the scale of millennia" (Personal communication with R Sengupta, October 12, 2010).

River basin planning has long been viewed from a management perspective as an ecologically-sound and economically cost-effective means of reconciling the conflicting objectives of development and conservation (Wengert 1985). Rivers are integrators of the landscape that they drain. So hydrological, geomorphological and biological assessment can provide indicators of ecological health across broad spatial scales (Allan and Johnson 1997; Riseng et al. 2010). In 1890s John Powell, an American land use planner, proposed organization of water management by basin-scale as essential concomitants of a wise development plan (Grantham et al. 2008), which was never implemented. In the Tennessee Valley, basin-scale management agencies are not existent or have little power. There is very little geographical integration as well as interdisciplinary integration in the management of water resources (Grantham et al. 2008).

River valley projects were seen as symbols of social development and technological achievement in the mid-century. From 1960 onwards several investigations were initiated globally for a number of projects such as the Kariba, Volta, Aswan, and Lower Meckenzi. By 1970, however, criticism of large river-valley projects from different angles became increasingly common. Dams provide many benefits by reducing flood flows, providing irrigation water, and securing the life of people in downstream sectors by generating electricity. But with these benefits come environmental consequences i.e. changing flow regime, eroding river banks and river sandbars, and concerns for safe recreational use. Despite their benefits, it is undeniable that control structures strongly impact the natural environment and lives of people, often in very negative ways (McCully 2001; Dharmadhikary 2005, 2008; D'Souza 2006, 2008; Molle et al. 2009; Baghel and Nüsser 2010).

There has been intense social and environmental debate worldwide about the need for water control structures and ways of mitigating their negative impact. Recently the Narmada Valley project in India and the Three Gorges dam of China have provoked bitter controversy. In some cases, existing dams have even been decommissioned in parts of the developed world. Criticism of large dams, endorsed to some extent by the 2000 World Commission on Dams (WCD) report, overlooks pressing problems in developing countries that are addressed by large dams. It is recognized that a number of environmentalists and non-governmental organizations (NGOs) have played a vital role in increasing the awareness of dam engineers and supporting them in planning environmentally sustainable dam projects. On the other hand, there have also been demands for total cessation of all dam construction (Gupta 1998). According to Gupta (1998),

> If these directives on dams would have strictly been followed during the 20th century, there would not have been most of the existing, even well planned, designed and constructed

> major dams and hydropower projects, providing the needed additional water sources, flood control, protection against drought, and power generation around the world.

This would have severely hampered the development of many countries. A recent careful evaluation of the Aswan Dam's impact on Egypt concludes that it has been overwhelmingly beneficial to the country (Biswas 2003). The Sunday Express (2003, June 8th Edition) stated that the positive impact of the Narmada dam project has finally been recognized. The current debate on CO_2 reduction through hydropower revitalizes the global discussion of large dams by placing them as so called "green" alternatives (Baghel and Nüsser 2010).

I believe that the Damodar river control project, like many others, has been extremely beneficial (Tables 3.5 and 3.6). The DVC has developed a large number of thermal power plants which are a major supplier of electricity in the region encouraging huge industrial growth. Irrigation potential has been drastically increased (Bhattacharyya 2002). In the Damodar River, human intervention through control structures has augmented the resource potential of the river and the dependence on the Damodar has increased over the years with increasing encroachment on the riverbed. The geo-fluvial resources, a series of sandbars on the river, were once perceived as unproductive by the local agrarian community. People previously used those resources only in the form of silt but now the semi-fluid or flexible resource have been exploited into a permanent resource in the form of productive sandbars (Bhattacharyya 2008a, b). Professor M. Gordon (Reds) Wolman while talking about riverbed settlers of the Damodar River, wrote (personal communication, January 11, 2007) "The land use, cropping and settlement patterns, at a micro level, represent a sophisticated understanding of the flood regime and opportunities to maximize the productive capacity of an unpromising environment". While people benefit, however, the river ecosystem deteriorates and we need strategies to safeguard this valuable ecological resource as well. The lower parts of the Lower Damodar i.e., Amta channel, has deteriorated so much that it cannot cope with excess water released from an upstream reservoirs. It is too early to state conclusively that excessive aggradation is due to control structures since, in the studied section, sediment is also supplied from an extensive unconfined section, particularly in the Ranigunj coalfield area. What must be noted is that the entire physical system should be taken into account before the impact of river control measures or human impact on the downstream environment is assessed. Insights gathered from geomorphologists may be useful but flood and water resource management requires a comprehensive approach to floodplain problems and a synchronized effort by geomorphologists, geologists, ecologists, water resource engineers, land use planners, economists, foresters, recreation and environmental specialists, and riparian communities.

Reviewing the history of floods and flood control in the Lower Damodar, it is clear that doing away completely with floods is neither possible nor desirable. Despite great success in the reduction of floods, they remain problematic and potentially devastating as in 1978. Furthermore, even if a river could be brought under complete control, a total lack of floods would only lead to ecological deterioration of the river system as is evident in the Lower Damodar River. It is important to remember that, with a dam in place, we forego an entirely natural environment below a dam (Collier et al. 1996). The responsibility of ensuring the ecological health of the river, therefore, falls on us. Doyle et al. (2005) has also outlined this reduced range of floods on ecosystem processes. Clearly, an alternate perspective is needed; one that views the river more as an ally than an adversary, one that apprehends not only the hazards of floods but also the benefits. The goal should be not to eliminate floods but to incorporate them within our water management strategy, as with "flushing floods" discussed below. Only such an intelligent strategy, based more on understanding of the river system than solely on the attempt to control, can ensure a balanced and sustainable outcome in meeting the diverse needs of the people who live with the river.

Many impacts of dams are technologically impossible to mitigate if dams are to offer their planned benefits (Bergkamp et al. 2000). The WCD recommended thorough periodic reevaluation of the facilities, operation and performance of dams every 5–10 years (River Revival Bulletin No 22, Nov 29, 2000). While addressing large dams, the WCD has also identified programs to restore, improve, and optimize benefits from existing dams (WCD Report, Nov 2000). The WCD model was regarded widely as a unique experiment in global public policy making (Srinivas 2001; Bandyopadhyay 2002; Bandyopadhyay et al. 2002; Brinkerhoff 2002; Dubash 2009). The country review studies prepared by the WCD on Dams, however, were deemed unsatisfactory by many countries and water professionals as stated before.

Within the last decade, river resource management policy has undergone a major paradigm shifts (Pahl-Wostl et al. 2007) from an initial focus on water chemistry to increased acknowledgment of the importance of aquatic ecology and the role of geomorphology in balancing riverine ecosystem function (Grantham et al. 2008). The concept of a river basin as a management or planning unit reemerged in the 1990s as a foundation stone of integrated Water Resources Management (IWRM), enriched and intermingled with watershed and ecosystem management approaches (Molle 2006). The European Union's Water Framework Directive (WFD) defines a new strategy for meeting human demands while protecting environmental demands and values and may be helpful in informing water management practices and policies in different regions of the world. The WFD sets focus on basin-scale, public participatory and environmental economics approaches as well as establishes a holistic environmental assessment method according to which water status is defined by its ecological, chemical and in the case of ground water, quantitative status (WFD 2000; Grantham et al. 2008). Maybe we can think of better human environment interactions through holistic watershed management i.e., "treating the catchment areas, harnessing waters before they reached the major rivers and establishing vegetative cover were felt to be better suited for flood management" (Lacy 2006), and "Integrated water resources management (IWRM)" which is "now recognized across the world as the process to promote the coordinated development and management of water, land and related resources in river basins, to maximize the economic benefits and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (Pangare et al. 2009). Keeping this in view, some recommendations for the Damodar River are provided below.

1. One vital area of emerging scientific knowledge is the assessment of “flushing floods” (DVC 1957a), “beach building flows” (Schmidt 1992), “habitat-maintenance flow” (US Department of Interior 1995), 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). For the maintenance of the downstream ecosystem, there is a need for flushing floods. In fact, this was suggested earlier by the DVC itself (DVC 1957a). Flushing of the early storms through the reservoirs will help scour the main channel and, at the same time, will route the sediment-laden flow through the impoundment. At the end of the flushing period, the bottom sluices are closed and reservoirs are operated normally until the end of the next dry season when the same process can be repeated. In India, where many dams lack the high-capacity bottom sluices required for flushing, reconstruction would be required to provide sediment-proof low level outlets. Though it is expensive, reconstruction is less costly than dredging or abandonment of reservoirs (Morris 1995). Sediment routing during the first half of the monsoon months has not been successfully employed in India and in the DVC. In order to preserve the long-term storage capacity of reservoirs, it is necessary to pull the reservoir down to a low level at the beginning of the monsoon. On the other hand, in order to maximize the power generation, it is desirable to maintain the water level over the turbines at the highest possible level. Moreover, irrigation and power have opposing claims and their demand does not coincide. As an instance, the Damodar Valley Corporation (DVC) wants to operate the dam for optimization of power benefits, whereas the West Bengal Government wants more water for irrigation downstream (Bhattacharyya 2003).
2. Previously the Lower Damodar used to adjust with excess discharge through a well defined distributary system on the left and spill channels on the right. The connection between the Damodar and the distributary channels must be revived. Connection between the Damodar and the Banka must be restored. The artificial separation of the Banka from the mother stream has increased flood hazards in the Banka basin. So re-opening of the Jujuti sluice may solve this problem. According to Opperman et al. (2009), reconnection to rivers is helpful for sustainable floodplain management.
3. Embankments should be properly maintained during life span of the barrage and reservoirs. To cope with shifting banklines, embankments are usually retired. On the Amta Channel, multiple retirements have been observed on the left bank. But more important is the proper maintenance of the embankments. It is suggested, therefore, that earthen embankments be strengthened using soft engineering approaches. Embankments should be clothed with vegetation.
4. Had all the eight DVC dams been constructed or taken up per design assumptions, the design flood would have been moderated to 7,080 m^3/s. While the four dams have served their purpose, the lower part of the Amta channel is not capable of carrying a discharge of 849.6 m^3/s. Despite control structures, drainage congestion is still a problem below Paikpara, thus underlining the need

for an immediate solution of the problem of drainage congestion of the lower reaches in order to derive the maximum benefits of flood moderation. A separate drainage scheme is required for the Amta channel.

5. A permanent thalweg is needed to maintain a perennial thalweg flushing flood. Perenniality of the thalweg can be achieved if a more uniform streamflow pattern is maintained and extreme seasonal peak streamflow is evened out by creating some check dams. Controlled releases should be maintained without excessive flooding of the populated char lands while at the same time sustaining sufficient channel capacity to carry many common floods of frequent recurrence (personal communication with M.G. Wolman, April 10 1996).
6. Careful analysis of storage requirements, adequate management, and proper distribution of floodwater should be emphasized. There is a need for integrated flood management, with coordinated development and management of water, land, and related resources in the basin/sub-basin as a means of restoring at least active channel areas and geomorphic complexity of the shrunken systems downstream (Graf 2006).
7. The most crucial problem in the Lower Damodar, however, is that of anthropogenic stabilization of the active riverbed by the riverbed occupiers. The problem has taken a different dimension as most of the riverbed occupiers are Bangladeshi refugees. Refugee issues are very sensitive ones, and always politicized. Since many other riverbeds in West Bengal have become second homes of the refugees, colonization in the riverbed and stabilization of bars due to year-long cultivation are no longer local issues but also have regional dimensions. Lowering river water-level for quick-growing vegetables is a common seasonal practice throughout India. A few huts of rudimentary structure are always to be seen when riverbeds are put to agricultural uses. It is possible that some of the riverbeds of seasonal rivers of India will be occupied permanently in the near future due to population pressures and food crises. Increasing demand for space creates a pressure to utilize hazard zones, including flood-prone areas (Bird 1980). So it is not unlikely that riverbeds in other countries, particularly in tropical countries, will be occupied for permanent settlements and transient sand bars will become immobile causing channel deterioration. Stabilization of bars may have fortified the resource base of riverbed occupiers, but the Lower Damodar ecosystem has deteriorated. Other riverbeds of the Ajay, Bhagirathi-Hooghly, and Mahanadi with settlements may meet the same fate today or tomorrow. That is why it is crucial to settle the question of allowing permanent use of the active riverbed.

Relocation and resettlement of displaced populations for dam closure have always been a problem all over the world. Resettlement problems of active riverbed populations are of equal significance, if not more, particularly when the riverbed users are refugees. When the DVC was conceived these problems were not anticipated. In the case of the Lower Damodar the government's decision on land ownership issue in the active riverbed is not above criticism as permanent use of active riverbed has become detrimental for the river itself. Following are measures that can be taken to solve these problems:

   a. Further encroachment on the active riverbed should be discouraged and a rational refugee rehabilitation policy is required.
   b. Active riverbeds, floodplain and wetlands with the greatest ecological value should be delineated properly. Proper measures should be taken to avoid impacting active riverbeds and wetlands during development of char lands and floodplains. Increase of storage in the river system through floodplain and wetlands helps trapping more water in the catchment, thus lowering flood peaks (Kundzewicz and Kaczmarek 2000).
   c. DVC should be very much aware of the problem of misuse and mismanagement of catchments and should take initiative to identify the priority area for catchment treatment as well as implementation of programs to lessen soil erosion and sediment generation (Chaudhuri 2006). Natural resources evaluation as well as public awareness must play a part in their reduction (Douglas 1981).
   d. The knowledge of people in evaluating and managing their environment should be an important element of a comprehensive and participatory approach to flood management (Correia et al. 1998). The lack of efficient community participation is a significant barrier in developing regional governance strategies (O'Toole et al. 2009) and the involvement of the community in environmental monitoring should be an essential part of sustainable catchment management so that their interests are aligned with the aims of the project and they feel committed to the success of the endeavor.

8. Apart from the anthropogenic changes mentioned so far, the climate itself is being changed in ways we are just beginning to recognize. It is reported (Pottinger 2010) that catastrophic flooding in Pakistan, dam breaks around the world, and drought-caused blackouts in Africa provide profound threats to our hydrological cycle and changes in river systems (Goudie 2006b). It poses danger to biodiversity and ecosystem services (Turner et al. 2010) and tens of millions of people are going to be displaced within this century (Dasgupta et al. 2009). "It's something that's been neglected, hasn't been talked about and it's something the world will have to do," said Rajendra Pachauri, chairman of the Intergovernmental Panel on Climate Change. "Adaptation is going to be absolutely crucial for some societies." (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. This is also true for our Damodar River basin. Roy and Majumdar (2005) studied the impact of climate change on water resources of the Damodar River basin and observed that seasonal shifts in streamflow and precipitation pattern, changes in temperature will have a significant negative impact on river ecosystem.
9. After the 2000 flood in West Bengal, UNICEF initiated a program of "Community Based Disaster Preparedness (CBDP)." This type of CBDP and adaptation programs must be encouraged with easy access to information. An

adaptation strategies database should be developed based on long-standing adaptation strategies and community-developed knowledge from the riparian communities who have adapted to fluctuating flood regime in the Damodar riverbed.

10. An emphasis on non-structural measures including land use planning, flood plain zoning, flood proofing and developing a culture of community-based disaster preparedness should be the backbone of the program for the integrated river basin management (Bhattacharyya 2011 and personal communication with Ray C. February 15, 2008).
11. The Russian River case study in California demonstrates that WFD is not a ‘silver bullet’ that provides “simple solutions to challenging problems” but the “WFD can provide a useful 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” (p, 85; Grantham et al. 2008).
12. It is suggested, therefore, regional preparation for large-scale, systematic hydrological/ecosystem responses and mitigation when possible must join site-specific conservation and restoration as key foci in the management of the Damodar watershed. To first understand and then encourage effective preparation for systematic hydro-ecological and climate changes in the Damodar watershed we need an integrated, scale-flexible, analysis and information sharing system to bring the best available-science to bear on the combined impacts of consumptive water use, land use and climate change (Wiley et al. 2010).

8.2 The Need for Integrating Watershed Science and Management

Policy makers in the domain of flood and water resource management are faced with the enormously challenging task of parsing vast amounts of data to arrive at rational decisions that affect the lives and livelihoods of millions. The scope and scale of these problems make accessible decision support systems linking scientific databases, modeling analyses and Geographic Information Systems (GIS) processing, a necessity. GIS is 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 Domodar include: how much water do we now have in the river, how much we are using, and how much we will need later (Maidment 2002), as was also asked by Prof. M. Gordon (Reds) Wolman (Kobell 2007). Therefore, there is an urgent need to compile and update flood- and water-related data and to make them systematically available through computerization. GIS can play a key role in making the data and their analysis explicable to both managers and public where these can be integrated into a public and participatory conversation about the future.

Risk analyses 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 a coherent basin-wide, integrated analytical framework for both hydro/ecological and social impact forecasting (e.g. Wiley et al. 2010). Such a framework could make use of extensive use of GIS technologies both to perform analyses and effectively communicate.

The risks and uncertainties inherent for communities living in close symbiosis with a river system are large. Natural flood hazards and variability in geomorphic process are compounded by larger scale forces of climate change, regional land cover transformation, and changing political will for expanding and/or maintaining existing engineering infrastructure (Personal communication with M. J. Wiley, July 15, 2009, October 6, 2010 and S Vaddey, July 28, 2009).

Changes in land use and climate along with hydro regime management scenarios can be quantitatively evaluated and graphically depicted providing a unified “model” for local and regional discussions of 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 (personal communication with M. J. Wiley, July 15, 2009, October 6, 2010).

The Lower Damodar, a small part of the greater Damodar river system, is located in West Bengal, India but the findings on the controlled Lower Damodar are relevant to river communities across India and elsewhere (Bhattacharyya 1998). In this age of heightened environmental awareness, we all know that the survival of our civilization depends on rational and constructive maintenance and use of our water resources. The major challenge in the coming decades is to develop a holistic and sustainable water management system that will be environmentally accountable, socially acceptable and economically feasible. River resources should be treated as economic assets since ongoing economic development depends on a riverine regime that is ecologically sound and socially just (Saha and Barrow 1981). The primary issue to be addressed, therefore, is not whether dams are needed but how a river system is cared for in the presence of dams, floods and riparian communities. These worthwhile goals, however, will remain out of reach unless we have effective government policy and the legal structure to support it.

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Appendix A
List of Reference Maps

List of Mouza *(A Land – Settlement Division of an Area)* Maps

Police station	Name of Mouza	J.L. No.	Police station	Name of Mouza	J.L. No.
Nituria	Saltora		Barddhaman	Jujuti	158
				Chanchai	46
Mejhia	Japamali	70		Chak Tentul	16
	Jalanpur	74		Rhondia	4
	Banjora	73		Gopalpur	121
	Jangpur	72		Konerpur	161
	Sarama	71		Dadpur	123
	Dighalgram	69		Nala	20
	Purbator	67		Belkas	21
	Debagram	66		Baharpur	22
	Damodarmohan	64		Idilpur	45
	Balarampur	63		Fakirpur	25
	Purunia	62		Kanchanagar	26
	Murra	61		Bangpur	32
	Telenda	60		Mirchhoba	33
	Mejhia	37		Becharhat	79
				Shrirampur	80
Barjora	Pratappur	15		Hatsimul	81
	Sitarampur	16		Kanthalgachi	83
	Paharpur	51		Chaitpur	84
	Krishnanagore	52		Amirpur	85
	Bamandihi	53		Manikhati	108
	Purakunda	54		Kalinagore	160
	Tajpur	56			
	Pakhanna Bhairabpur	57			
	Pakhanna	58			
	Gopalpur	59	Galsi	Gohagram	70
	Radhakantapur	60		Dakshin	114
				Bhasapur Sonda	116
Patrasair	Uttar Patashpur	1		Sikarpur	117
	Deulpara	2		Dumur	120
	Khanpara	27		Jujuti	158

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Police station	Name of Mouza	J.L. No.	Police station	Name of Mouza	J.L. No.
	Tashuli	28		Merual	159
	Ghoradanga	29		Konarpur	161
	Uttar Gobindapur	30			
	Panchpara	60			
	Mamudpur	61			
	Salkhara	64			
Sonamukhi	Palashdanga	1	Jamalpur	Paikpara	66
	Joynagar	2		Ujirpur	69
	Alampur	4		Dhapdhara	64
	Dihipara	5		Sonargeria	65
	Rangamatia	8		Muidipur	67
	Kenety	9		Haragobindapur	40
	Nityanandapur	10			
	Beloa	108			
	Amritpara	136			
	Beshia	138			
	Bara	139	Memari	Palla	45
	Palsura	140		Chanchai	46
	Rupuisar	134			
Indus	Somsar		Khondoghosh	Gaitanpur	65
				Atkulla	64

Topographic Sheets (SOI Maps) and Images

1: 15,000

79 B/13/2

1:25,000

73 I /14 NW, 73 I /14 NE, 73 M/2 NW, 73 M/2 NE, 73 M/7 NW, 73 M/7NE, 73 M/7 SE

1:63,360, 1: 50,000

73 I/10, 73 I/14, 73 M/2, 73 M/6, 73 M/7, 73 M/10, 73 M/11, 73 M/15, 73 M/16, 79 A/4, 73 N/13, 73 N/14, 73 N/15, 79 B/3

1: 250,000

73 I, 73 M, 73 N, 79 A, 79 B

IRS geocoded imagery 73 M/2, date and year of acquiring 10 May 1992, 1: 50,000

IRS geocoded imagery 73 M/7, date and year of acquiring 09 Nov 1992, 1: 50,000

Satellite image of 1994 [IRS-IB LISS-2/FCC/classified image (1:100,000)] and 2003 LISS-3 scenes of IRS-ID satellite (1:100,000).

Details of 2003 satellite image: IRS-1D, Sensor: LISS-3, Resolution: 23.5 m, Date of Pass: 23-Jan-2003, Path: 107, Row: 55, Bands: Green, Red, NIR & SWIR.

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Appendix B
Hydrological Observation

Damodar River Streamflow Data

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 1993–2007 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 the UNESCO, Vol. 11, 1971; Vol. 111, 1971; Vol. 111 (Part 111), 1979; Vol. 111 (Part IV), 1985 (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 total annual streamflow data from 1953 to 1955 and 1969 to 2007 at the Damodar bridge site, situated approximately 29 km downstream of Panchet Dam, have been collected from the Hydraulic Data Division, DVC, Maithon. Data for the years 1972, 1973, 1977, 1979, 1980, 1982, 1987, 1988 and 1990–1992 are not available.

The record of peak streamflow for the Damodar River at Rhondia is available from 1823 to 1917 as a discontinuous series and from 1933 to 2008 as a continuous series. This data provide a valuable index of flood recurrence in the Lower Damodar River. The annual peak streamflow data for the River Damodar at Rhondia are available from 1823 to 1933 as a discontinuous series from the National Commission of Flood, Vol. 2. The same data for 1934–1960 are published by UNESCO, Vol. 11, 1971 and for 1960–2008 from the Damodar Canals No. 11, Subdivision–Rhondia, Barddhaman.

The volume of water released from the Durgapur barrage situated approximately 74 km downstream of Panchet Dam have been collected from the Irrigation and Waterways Department, Government of West Bengal at Kanainatshal, Barddhaman. This data includes monsoon (June–October) and non-monsoon period (November–May) from 1968–1969 to 1999–2000. It also includes the volume of water released through the canals (left bank and the right bank main canals) from the barrage for kharif (summer crop), rabi (winter crop harvested in spring) and boro (paddy) seasons. The inflows into the barrage and canal consumption have been computed from the data available from the Hydraulic Data Division, DVC, Maithon.

Inflow and Out Flow Data

The data for the combined peak inflow and outflow from the (Maithon and Panchet reservoirs) for the years 1986–1994 have been collected from the DVC Data Book (1995). The same data for the years 1995–2007 have been collected from the Hydraulic Data Division DVC, Maithon.

Suspended Sediment Concentration Data

Information about suspended sediment concentration for the period 1952–1955 and 1981, 1984, 1985, 1986, 1987, 1988, 1991 & 1996–2001 have been computed from daily average suspended sediment concentration data provided by the Hydraulic Data Division DVC, Maithon. Such data has been used in specific cases to show dam related changes in suspended sediment concentration. Reservoirs sedimentation data for DVC reservoirs have been collected from DVC and CWC (Central Water Commission) Reports and also from individual study reports.

Measured Cross Section

Measured cross-sections of the Damodar River have been collected from the Hydraulic Data Division, DVC, Maithon and from the Irrigation and Waterways Department, Government of West Bengal. All measured cross sections are referenced to elevation above sea level.

Rainfal

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 analyzed.

Appendix C
Streamflow of the Lower Damodar River at Rhondia (Monthly and Average Annual Streamflow Total in m^3/s)

Year	Months (Mar–May)	% to annual total	Months (Jun–Sept)	% to annual total	Months (Oct–Nov)	% to annual total	Months (Dec–Feb)	% to annual total	Average annual total
1934	9	0.44	1,822	88.79	121	5.90	100	4.87	2,052
1936	14	0.34	3,247	79.99	690	16.99	23	0.57	4,059
1937	107	3.27	2,369	71.99	585	17.85	309	9.43	3,277
1938	35	1.33	2,375	90.34	151	5.74	72	2.74	2,629
1939	27	0.59	3,930	85.34	524	11.38	33	0.72	4,605
1940	110	4.27	2,218	86.17	153	5.94	177	6.88	2,574
1941	21	0.48	3,249	74.93	984	22.69	46	1.06	4,336
1942	75	1.32	5,338	94.01	206	3.63	105	1.85	5,678
1943	1	0.02	3,798	88.04	493	11.43	4	0.09	4,314
1944	33	0.90	3,240	88.57	296	8.09	88	2.41	3,658
1945	28	0.78	2,610	73.05	830	23.23	99	2.77	3,573
1946	159	2.69	4,964	84.02	692	11.71	38	0.64	5,908
1947	40	0.97	3,408	82.74	570	13.84	153	3.71	4,119
1948	31	0.73	3,256	77.43	756	17.98	86	2.05	4,205
1949	260	4.78	4,767	87.64	324	5.96	171	3.14	5,439
1950	25	0.46	5,233	95.56	179	3.27	44	0.80	5,476
1952	84	2.26	3,016	81.05	587	15.78	13	0.35	3,721
1953	22	0.38	5,179	88.47	538	9.19	101	1.73	5,854
1954	24	0.87	2,422	87.63	246	8.90	89	3.22	2,764
1955	39	1.68	1,895	81.65	293	12.62	80	3.45	2,321

Year	Months (Mar–May)	% to annual total	Months (Jun–Sept)	% to annual total	Months (Oct–Nov)	% to annual total	Months (Dec–Feb)	% to annual total	Average annual total
1956	43	0.91	3,322	70.38	1166	24.70	97	2.06	4,720
1957	68	2.37	2,508	87.27	111	3.86	273	9.50	2,874
1958	197	7.98	1,213	75.42	279	11.30	106	3.69	2,869
1959	178	3.03	3,091	52.68	2284	38.93	198	3.37	5,867
1960	334	9.10	2,082	56.73	891	24.28	442	12.04	3,670
1965	218	11.63	1,405	74.97	158	8.43	181	9.66	1,874
1966	169	37.56	208	46.22	22	4.89	52	11.56	450
1967	9	0.34	2,558	96.27	66	2.48	23	0.87	2,657
1969	134	7.35	1,581	86.73	35	1.92	68	3.73	1,823
1970	24	0.92	1,816	69.66	689	26.43	63	2.42	2,607
1971	195	2.60	6,559	87.59	572	7.64	99	1.32	7,488
1972	81	7.56	864	80.60	31	2.89	194	18.10	1,072
1973	25	0.65	2,051	53.18	1543	40.01	8	0.21	3,857
1974	76	2.70	1,871	66.44	665	23.62	433	15.38	2,816
1976	45	2.51	1,611	90.00	101	5.64	29	1.62	1,790
1977	105	2.04	4,936	95.75	97	1.88	16	0.31	5,155
1978	63	1.47	2,862	66.57	1319	30.68	20	0.47	4,299
1979	164	23.56	498	71.55	13	1.87	59	8.48	696
1982	10	2.57	345	91.25	14	3.71	12	3.17	379
1983	11	0.87	723	56.97	509	40.11	8	0.63	1,269
1984	80	1.55	5,052	97.68	23	0.44	32	0.62	5,172
1985	19	0.92	1,286	62.31	667	32.27	26	1.26	2,064
1986	40	1.48	1,893	70.00	649	24.00	144	5.31	2,710
1987	22	0.65	3,236	95.49	95	2.80	70	2.07	3,389
1988	47	2.29	1,819	88.99	128	6.26	41	2.01	2,044
1989	40	2.07	1,600	82.82	226	11.70	58	3.00	1,932
1990	265	6.23	2,839	66.80	1068	25.12	68	1.60	4,250

Year	Months (Mar–May)	% to annual total	Months (Jun–Sept)	% to annual total	Months (Oct–Nov)	% to annual total	Months (Dec–Feb)	% to annual total	Average annual total
1991	125	5.71	1,694	77.42	200	9.14	133	6.08	2,188
1992	59	6.07	762	78.39	68	6.99	150	15.43	972
1993	161	7.58	1,469	69.07	341	16.01	115	5.41	2,127
1994	58	1.91	2,625	87.00	212	7.04	99	3.28	3,017
1995	44	1.42	2,383	76.45	546	17.52	114	3.66	3,117
1996	92	3.17	2,706	92.89	60	2.06	137	4.70	2,913
1997	119	3.22	3,187	86.64	184	5.00	67	1.82	3,678
1998	239	7.24	2,231	67.57	545	16.51	296	8.96	3,302
1999	93	1.72	4,093	75.68	956	17.68	224	4.14	5,409
2000	226	8.18	2,152	77.80	189	6.84	310	11.20	2,767
2001	66	2.87	1,954	85.42	144	6.29	114	4.98	2,288
2002	85	5.13	1,127	68.52	303	18.44	117	7.11	1,645
2003	127	6.44	945	47.92	804	40.77	194	9.83	1,973
2004	50	2.84	1,269	71.63	362	20.41	91	5.14	1,772
2005	88	8.58	656	64.21	188	18.38	79	7.73	1,022
2006	74	2.2	2,820	84.47	329	9.87	106	3.18	3,338
2007	104	1.91	4,354	80.34	631	11.64	118	2.18	5,419

Processed data after K. Bhattacharyya (1998).

Appendix D
Streamflow of the Lower Damodar River at Damodar Bridge Site

Year	Months (Mar–May)	% to annual total	Months (Jun–Sept)	% to annual total	Months (Oct–Nov)	% to annual total	Months (Dec–Feb)	% to annual total	Average annual total
1953	1,135.61	1.18	87,813.52	90.95	4,882.03	5.06	2,716.2	2.81	96,547.36
1954	884.8	1.75	44,188.16	87.44	3,474.47	6.88	1,986.37	3.93	50,533.8
1955	2,334.56	5.49	31,601.98	74.36	5,995.52	14.11	2,568.75	6.04	42,500.81
1969	4,348.73	7.00	45,442.56	73.18	8,825.32	14.21	3,478.69	5.60	62,095.3
1970	2,694.04	3.58	56,232.42	74.78	13,051.3	17.36	3,213.05	4.27	75,190.81
1971	5,312.77	3.53	132,055.86	87.75	9,535.57	6.34	3,591.04	2.39	150,495.24
1974	7,908.41	10.79	46,763.95	63.83	14,079.73	19.22	4,509.08	6.15	73,261.17
1975	10,486.45	12.43	50,667.13	60.11	14,252.44	16.91	8,890.33	10.55	84,296.35
1976	9,221.52	14.31	41,112.12	63.78	7,640.53	11.85	6,481.31	10.06	64,455.48
1978	8,077.29	5.81	94,680.83	68.11	30,134.62	21.68	6,116.21	4.40	139,008.95
1981	5,843.11	9.63	41,722.16	68.76	10,791.5	17.78	2,322.61	3.83	60,679.38
1984	2,258.19	1.61	129,867.02	92.30	5,966.07	4.24	2,605.87	1.85	140,697.15
1985	4,735.64	4.68	57,815.91	57.24	29,497.45	29.20	8,963.58	8.87	101,012.58
1986	15,338.39	12.88	73,276.9	61.55	20,801.2	17.47	9,635.37	8.09	119,051.86
1989	3,540.91	5.03	50,904.89	72.26	13,428.16	19.06	2,573.16	3.65	70,447.12
1993	2,622.96	6.94	26,898.64	71.22	7,029.3	18.61	1,219.81	3.23	37,770.71
1994	3,157.22	3.62	71,451.07	81.99	10,236	11.75	2,301.72	2.64	87,146.01
1995	2,537.34	3.64	57,258.5	82.13	8,830.49	12.67	1,092.05	1.57	69,718.38
1996	3,473.73	5.25	58,342.83	88.20	3,389.81	5.12	941.75	1.40	66,148.12
1997	316.61	0.44	68,160.29	94.76	2,391.09	3.32	1,065.02	1.50	71,933.01

Year	Months (Mar–May)	% to annual total	Months (Jun–Sept)	% to annual total	Months (Oct–Nov)	% to annual total	Months (Dec–Feb)	% to annual total	Average annual total
1998	3,414.19	6.18	43,788.9	79.29	7,247.38	13.12	773.72	1.40	55,224.19
1999	874.94	0.98	75,038.82	83.85	12,953.17	14.47	621.67	0.69	89,488.6
2000	1,069.91	3.38	28,562.96	90.17	1,509.61	4.77	535.36	1.69	31,677.84
2001	136.01	0.42	29,311.74	90.94	2,449.92	7.60	332.88	1.03	32,230.55
2002	363.02	2.89	9,446	75.23	2,447.45	19.49	299.13	2.38	12,555.6
2003	389.38	1.70	9,264.39	40.47	12,959.95	56.62	276.35	1.21	22,890.07
2004	309.99	1.65	13,422.71	71.32	4,694.5	24.94	392.87	2.09	18,820.07
2005	302.12	3.34	7,577.39	83.75	887.5	9.81	280.15	3.10	9,047.16
2006	62.5	0.15	38,657.39	93.49	2,539.45	6.14	90.5	0.22	41,349.84
2007	143.12	0.23	56,608.82	91.79	4,872.63	7.90	46.5	0.08	61,671.07

Processed data after K. Bhattacharyya (1998).

Appendix E
Inflow into Durgapur Barrage and Canal Consumption (M.Cu.m)

Years	1961		1965		1971		1975	
Months	Inflow into barrage	Canal consumption	Inflow into barrage	Canal consumption	Inflow into barrage	Canal consumption	Inflow into barrage	Canal consumption
Jan	88.30	29.41	115.01	92.49	195.85	182.75	257.84	251.61
Feb	138.97	12.54	147.73	97.81	205.41	192.21	292.58	294.74
Mar	374.74	10.75	161.30	64.77	244.35	232.94	260.82	263.26
Apr	179.66	0.99	100.15	26.47	210.81	171.10	330.05	330.45
May	88.05	*Nil*	90.10	30.26	*N.A.*	*N.A.*	50.05	42.69
Jun	353.46	0.06	247.67	44.91	831.89	40.60	109.14	37.00
Jul	1,385.95	363.62	1,047.30	405.04	4,581.18	247.72	1,962.15	283.35
Aug	2,852.70	474.54	1,265.90	498.81	6,164.38	88.51	1,814.70	645.38
Sep	2,816.95	406.19	1,352.97	618.54	4,138.45	335.71	2,724.13	618.04
Oct	2,839.63	611.49	742.95	642.42	1,109.82	526.45	1,590.09	628.92
Nov	204.97	34.48	56.83	47.00	285.85	51.17	78.41	47.46
Dec	172.45	31.69	59.93	55.17	170.70	102.22	116.93	88.95

Years	1978		1980		1987		1991	
Months	Inflow into barrage	Canal consumption	Inflow into barrage	Canal consumption	Inflow into barrage	Canal consumption	Inflow into barrage	Canal consumption
Jan	170.34	154.68	37.88	38.23	121.79	118.28	246.82	128.71
Feb	245.44	244.72	31.67	35.77	209.25	215.90	214.96	194.54
Mar	243.60	245.27	38.92	38.23	205.63	216.00	325.48	326.24
Apr	231.16	229.89	46.24	36.51	249.18	258.25	247.74	309.15
May	95.72	43.06	53.47	38.23	99.10	38.23	114.18	87.09
Jun	582.00	37.01	545.96	37.00	333.99	37.00	268.11	37.00
Jul	1,084.05	416.96	1,928.45	189.34	1,749.38	348.46	617.23	217.52
Aug	2,797.43	531.00	2,242.22	629.06	3,551.25	431.07	1,511.87	532.52
Sep	5,132.86	495.80	2,888.57	710.75	4,920.03	366.90	2,910.02	420.07
Oct	3,115.51	247.28	778.29	589.79	735.01	666.88	711.56	545.82
Nov	343.46	232.68	138.18	45.05	102.37	69.22	192.12	63.00
Dec	212.05	96.49	158.32	97.25	84.88	67.40	164.13	57.60

N.A. = Not Available.
Processed data after K. Bhattacharyya (1998).

Appendix F
Peak Flow of the Lower Damodar River at Raniganj and at Rhondia (from 1933) during Pre-dam and Post-dam Periods

Peak flow

Pre-dam period

Year	Maximum discharge (m^3/s)	Date of peak discharge	Minimum discharge (m^3/s)
1823	18,406	–	–
1840	18,129	–	–
1855	9,911	–	–
1860	9,911	–	–
1864	9,628	–	–
1865	12,742	–	–
1866	11,894	–	–
1877	14,158	–	–
1878	6,230	–	–
1907	6,796	–	–
1913	18,406	–	–
1915	4,530	–	–
1916	11,185	–	–
1917	11,185	–	–
1933	6,480	–	–
1934	4,793	12 VII	0
1935	18,112	12 VII	0
1936	7,075	6 X	0
1937	5,876	31 VII	2
1938	12,002	6 IX	1
1939	7,989	4 VIII	1
1940	8,773	29 VIII	2
1941	17,942	10 X	1
1942	10,811	10 VIII	0
1943	8,384	5 VIII	0
1944	5,905	26 VIII	0
1945	4,514	22 X	0
1946	9,133	18 IX	1
1947	8,235	4 IX	1
1948	6,500	6 VIII	1
1949	7,696	12 VI	2
1950	9,561	18 VII	3

Peak flow

Pre-dam period

Year	Maximum discharge (m^3/s)	Date of peak discharge	Minimum discharge (m^3/s)
1951	1,1012	11 IX	1
1952	5,120	27 VII	1
1953	8,287	24 VIII	1
1954	7,407	8 IX	0
1955	1,714	28 VII	3
1956	8,579	26 IX	0
1957	5,658	3 IX	0

Peak flow

Post-dam period

Year	Peak discharge (m^3/s)	Date of peak dicharge	Minimum discharge (m^3/s)	Peak hours
1958	4,682	16 IX	14	–
1959	8,792	2 X	23	–
1960	3,389	30 VIII	17	–
1961	4,371	3 X	–	–
1962	1,926	8 VIII	11	–
1963	3,542	4 X	–	–
1964	1,977	12 VII	–	–
1965	2,811	30 VII	17	–
1966	502	3 VII	0	–
1967	4,138	19 IX	1	–
1968	3,391	14 VIII	–	–
1969	1,740	16 VIII	–	–
1970	3,782	11 IX	1	–
1971	4,556	17 VII	–	–
1972	1,434	15 IX	1	–
1973	5,726	13 X	1	–
1974	2,392	18 VIII	3	–
1975	3,855	20 VII	–	–
1976	5,297	19 IX	2	–
1977	4,156	30 VII	3	–
1978	10,919	27 IX	–	0 19–22 h
1979	413	21 VII	2	–
1980	4,210	28 VIII	–	at 18.00 h
1981	1,635	21 VII	–	at 18.00 h
1982	666	24 VIII	–	at 12.00 h
1983	2,098	10 X	–	at 15.00 h
1984	4,512	27 VI		at 02.00 h
1985	3,317	18 X		at 07.00 h

Peak flow				
Post-dam period				
Year	Peak discharge (m^3/s)	Date of peak dicharge	Minimum discharge (m^3/s)	Peak hours
1986	3,455	8 VII	–	at 15.00–2.001 h
1987	4,567	14 IX	–	at 11.00 h
1988	1,632	6 VIII	–	at 15.00 h
1989	1,933	5 VIII	–	at 18.00 h
1990	3,146	6 X	–	at 10.00 h
1991	2,184	5 IX	–	–
1992	1,443	28 IX	–	at 12.00 h
1993	3,816	15 IX	5.66	at 16.00 h
1994	3,298	1 VII	0	at 18.00 h
1995	6,522	29 IX	0	at 22.00–08.00 h
1996	3,627	9 VIII	0	at 15.00–20.00 h
1997	2,407	15VIII	0	at 3.00–18 h
1998	4,249	14IX	0	at 10–17 h
1999	5,690	25IX	0	at 5–8 h
2000	6,387	23IX	0	at 8–9 h
2001	1,859	2–3IX	0	at 18.00–18 hrs
2002	1, 858.7	29 IX	0	at 18.00 h
2003	2,496	28 X	0	at 3–9 h
2004	2,058	19–20 IX	0	at 21–18 h
2005	1,139.9	20 X	1.42	at 15.00 h
2006	7,035	24 IX	1.42	At 6–9 h
2007	8,883	25 IX	0	At 12.00 h

Appendix G

Combined Moderation by Maithon and Panchet Dams of the Damodar River

Date	Peak-inflow	Moderated out-flow	Flood moderation	% moderated
4.7.58	6,456.96	849.60	5,607.36	86.84211
12/13.8.58	3,568.32	906.24	2,662.08	74.60317
16/17.9.58	15,717.60	4,956.00	10,761.60	68.46847
11.7.59	3,794.88	2,010.72	1,784.16	47.01493
21/22.7.59	3,879.84	2,548.80	1,331.04	34.30657
10.9.59	3,879.84	2,860.32	1,019.52	26.27737
13.9.59	3,879.84	1,585.92	2,293.92	59.12409
1/2.10.59	17,643.36	8,156.16	9,487.20	53.77207
25/26.8.60	3,370.08	2,039.04	1,331.04	39.4958
30.8.60	4,899.36	2,945.28	1,954.08	39.88439
27.9.60	9,855.36	2,605.44	7,249.92	73.56322
22/23.8.61	3,115.20	1,812.48	1,302.72	41.81818
10/11.9.61	3,341.76	1,246.08	2,095.68	62.71186
2/3.10.61	14,613.12	4,559.52	1,0053.60	68.79845
25/26.7.62	3,313.44	1,246.08	2,067.36	62.39316
22/23.9.62	4,304.64	1,274.40	3,030.24	70.39474
28/29.9.63	6,117.12	1,161.12	4,956.00	81.01852
2/3.10.63	12,772.32	3,426.72	9,345.60	73.17073
24/25.10.63	13,168.80	2,577.12	10,591.68	80.43011
29/30.7.64	10,563.36	2,208.96	8,354.40	79.08847
24/25.9.64	5,664.00	1,954.08	3,709.92	65.5
19/20.8.67	5,664.00	1,529.28	4,134.72	73
26/27.8.67	4,417.92	2,124.00	2,293.92	51.92308
30/31.8.67	2,860.32	2,010.72	849.60	29.70297
4/5.9.67	5,154.24	1,472.64	3,681.60	71.42857
17/18.9.67	4,814.40	2,888.64	1,925.76	40
16/17.6.68	6,202.08	2,492.16	3,709.92	59.81735
2/4.8.68	5,748.96	2,322.24	3,426.72	59.60591
12/13.8.68	3,964.80	2,860.32	1,104.48	27.85714
9.8.69	5,352.48	311.52	5,040.96	94.17989
3/4.9.70	8,269.44	2,265.60	6,003.84	72.60274
10/11.9.70	4,361.28	2,860.32	1,500.96	34.41558
12/13.7.71	3,200.16	1,416.00	1,784.16	55.75221
16/18.7.71	12,007.68	5,125.92	6,881.76	57.31132
26/27.7.71	4,191.36	2,605.44	1,585.92	37.83784
3.8.71	3,115.20	1,416.00	1,699.20	54.54545
11/12.8.71	4,814.40	2,803.68	2,010.72	41.76471
29.8–1.9.71	6,400.32	2,775.36	3,624.96	56.63717

Date	Peak-inflow	Moderated out-flow	Flood moderation	% moderated
6/7.9.71	4,361.28	2,180.64	2,180.64	50
12.9.72	3,511.68	679.68	2,832.00	80.64516
23/24.9.73	5,975.52	2,265.60	3,709.92	62.08531
12/13.10.73	1,6652.16	4,956.00	1,1696.16	70.2381
16/17.8.74	3,766.56	1,897.44	1,869.12	49.62406
29/30.9.74	6,570.24	1,416.00	5,154.24	78.44828
17/19.7.75	7,788.00	2,832.00	4,956.00	63.63636
20.8.75	4,814.40	1,444.32	3,370.08	70
26/27.9.75	9,742.08	3,143.52	6,598.56	67.73256
17/19.9.76	8,411.04	4,616.16	3,794.88	45.11785
15.7.77	3,568.32	1,359.36	2,208.96	61.90476
28/30.7.77	8,241.12	2,888.64	5,352.48	64.94845
6.8.77	3,143.52	2,832.00	311.52	9.90991
27.9.78	2,1919.68	4,616.16	17,303.52	78.94057
27/28.8.80	9,657.12	4,219.68	5,437.44	56.30499
4/6.9.80	6,796.80	3,398.40	3,398.40	50
9.10.83	3,936.48	1,727.52	2,208.96	56.11511
23/24.6.84	6,966.72	2,973.60	3,993.12	57.31707
26/27.6.84	7,816.32	2,832.00	4,984.32	63.76812
7/9.8.84	4,446.24	1,982.40	2,463.84	55.41401
27/28.8.80	4,106.40	3,030.24	1,076.16	26.2069
4/6.9.84	3,313.44	2,407.20	906.24	27.35043
1.7.85	3,908.16	396.48	3,511.68	89.85507
17.10.85	5,182.56	2,435.52	2,747.04	53.00546
29/30.6.86	4,304.64	396.48	3,908.16	90.78947
7/9.7.86	4,389.60	2,832.00	1,557.60	35.48387
5.8.86	3,086.88	1,982.40	1,104.48	35.77982
6.7.10.86	4,304.64	2,152.32	2,152.32	50
26/29.8.87	6,060.48	3,398.40	2,662.08	43.92523
11/14.9.	6,853.44	4,531.20	2,322.24	33.8843
28/29.9.89	2,860.32	1,076.16	1,784.16	62.37624
5.7.90	2,973.60	368.16	2,605.44	87.61905
31.7.90	3,171.84	1,699.20	1,472.64	46.42857
2.8.90	3,030.24	2,293.92	736.32	24.29907
21.9.90	4,191.36	1,104.48	3,086.88	73.64865
5/6.10.90	3,794.88	2,718.72	1,076.16	28.35821
4.9.91	3,115.20	1,812.48	1,302.72	41.81818
29/30.6.94	5,550.72	2,803.68	2,747.04	49.4898
31.7.94	3,823.20	2,293.92	1,529.28	40
29.9.95	1,7360.16	7,080.00	10,280.16	59.21697
9.8.96	5,918.88	2,916.96	3,001.92	50.7177
23.7.97	5,748.96	1,699.2	4,049.76	70.44335
11.9.98	5,664	3,398.4	2,265.6	40
1999	10,300.00	3,400.00	6,900.00	66.99029
2000	10,800.00	5,700.00	5,300.00	49.07407
2004	5,300	1,700	3,600	67.92453
24.9.06	14,400	6,900	7,500	52.08333
25.9.07	11,100	7,500	3,600	32.43243
		56% reduction of Design flood		

Data Source: MRO, DVC, Maithon.

Appendix H
Model Questionnaire for Perception Survey

Respondent's name: Age:
Place of origin:

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1. When did you come to India?
2. Where did you arrive first?
3. How did you come to this riverine bar?
4. How did you come to know about these bars?
5. When did you come to these alluvial bars?
6. What were the conditions of the bars when you first came here?
7. Was it a barren sand bar?
8. Was it already settled?
9. What was your occupation in East Pakistan or in Bangladesh?
10. Did you have any flood experience in East Pakistan or in Bangladesh?
11. What is your experience about 1978 floods?
12. Do you think that the flood of the Damodar River is different from floods in Bangladesh?
13. Have you faced the floods of 1978?
14. Do you think that the embankments have ensured the safety of riverine bars?
15. What is your experience when water is released from the reservoirs?
16. Can you assess how much area will be inundated if water is released from the reservoirs
17. Do you think controlled release of water is safer than natural floods?
18. Can you identify the areas of probable bank erosion?
19. What measures do you take to arrest bank erosion?
20. Do you think that river-bed is always unsafe?

Personal Communication

Basu M. (1994) Personal communication through meeting dated 23 Feb. Ex. Reader, Department of Geography, The University of Burdwan, West Bengal, India

Ghosh D. (1997) Personal communication through meeting dated 14 Mar. Divisional Engineer, Damodar Valley Corporation, Kolkata, West Bengal, India

Ray C. (2008) Personal communication through meeting dated 15 Feb. Ex. Chief Engineer, Irrigation and Waterways Department (I&W), Govt. of West Bengal, West Bengal, India

Sengupta R. (2010) Personal communication through e-mail dated 12 Oct. Department of Geography, McGill University, Montreal, QC, Canada

Vaddey S. (2009) Personal communication through email dated 28 Jul. Portland District – Corps of Engineers, Portland, OR, USA

Wiley MJ. (2009) Personal communication through meeting dated 15 Jul. School of Natural Resources and Environment, University of Michigan, Dana Building, 440 Church Street, Ann Arbor, MI, USA

Wolman MG. (1996) Personal communication through e-mail/letter dated 10 Apr. January 11, 2007, Department of Geography and Environmental Engineering, The Johns Hopkins University, Baltimore, MD, USA

Color Plates

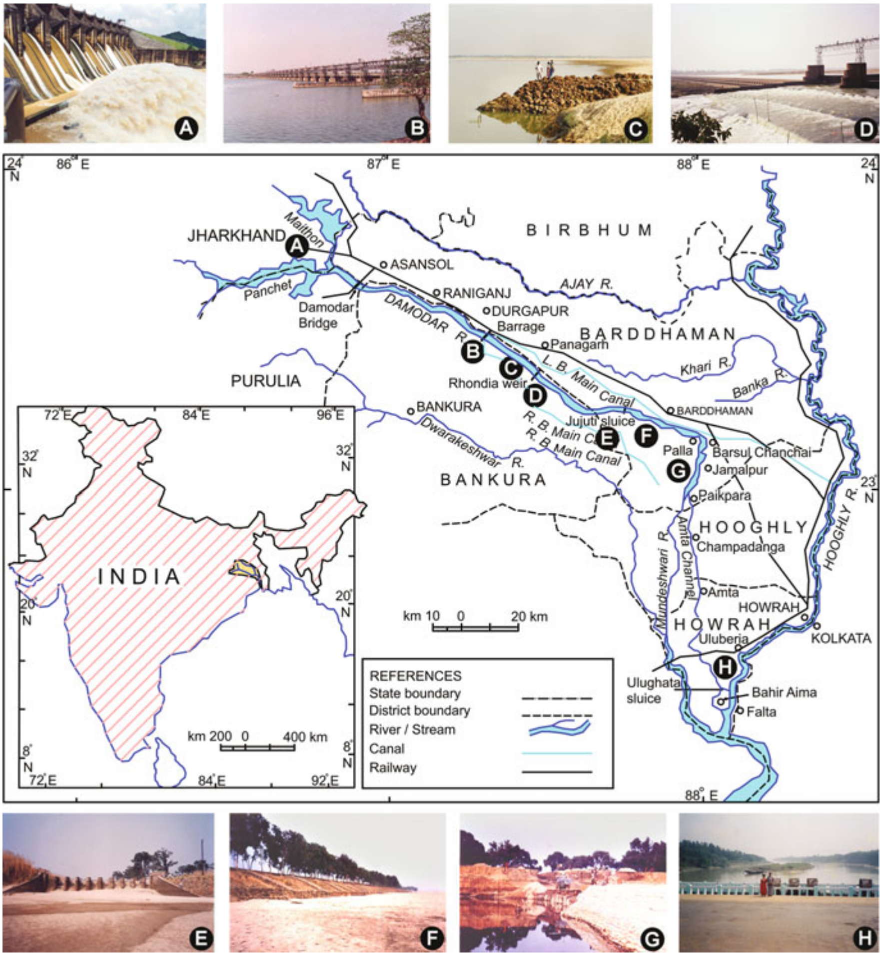

Plate 2.1 The Lower Damodar, a controlled river (control structures on the Damodar). (**A**) Maithon dam (Source: DVC, Kolkata). (**B**) Durgapur Barrage (Source: DVC, Kolkata). (**C**) Rangamatia Dyke (2000 photo courtesy: Bileswar). (**D**) Rhondia Weir (1996 photo courtesy: Durba Bhattacharyya). (**E**) Jujuti Sluice (1996 photo courtesy: Durba Bhattacharyya). Local people plugging Jujuti sluice by sand bags and Photo showing Jujuti sluice with closed lock-gates. (**F**) Embankment (1996 photo courtesy: Durba Bhattacharyya). River-bed with sandy bed load Earthern embankment strengthened with boulder pitching and strip plantation. (**G**) Breached left bank embankment for making a passage (1996 photo courtesy: Samir Ghosh). Temporary non-monsoon bridge has been constructed on the river bed for transporting sand quarried from the river bed itself. Note the piles of sand bags on both sides of the bridge. Heavy vehicle like lorry can ply over this bridge and left bank embankment has been breached for movement of vehicles. (**H**) Ulughata Sluice (1997 photo courtesy: Samapti Dhara). An excavated channel connecting Damodar with Hooghly

Plate 2.2 (**A**), (**B**) and (**C**) Perception survey (2000 photo courtesy: Bileswar). The perception survey technique has been applied to assess people's views on the control structures, consequent hydro-geomorphic changes, resource potential of alluvial bars and hazard risks in between control structures. Respondents were interviewed group-wise and individually

River Communities

Plate 5.1 (**A**) and (**B**) River communities (1996 photo courtesy: Durba Bhattacharyya)

Plate 5.2A River communities (2008 photo courtesy: Bileswar)

Plate 5.2B River communities (2000 photo courtesy: Bileswar)

Plate 5.2C River communities (2008 photo courtesy: Bileswar)

Facets of Riverbed Utilization

Plate 6.1 Dried-up channel used as village road and forms important component of land use (2008 photo courtesy: Bileswar)

Plate 6.2 Rice culture at Pallishri Squatters' Colony of Damodar Char Mohana (1997 photo courtesy: Durba Bhattacharyya)

Plate 6.3a Bara Mana becoming motorable during dry season (2002 photo courtesy: M Bharati)

Plate 6.3b Disconnected pools of channel D2 at north of Bara Mana during dry season (2008 photo courtesy: Bileswar)

Plate 6.4 Bank erosion below Durgapur barrage at Bara Mana (2002 photo courtesy: M Bharati)

Plate 6.5 Additional crop cultivation on nutrient poor fresh sand at peripheral zone (2008 photo courtesy: Bileswar)

Plate 6.6 Cocoon rearing at highest part of Bara Mana (1997 photo courtesy: Durba Bhattacharyya)

Plate 6.7a Linear settlements sited on higher parts of bars along the main road (2002 photo courtesy: M Bharati)

Plate 6.7b Thatched house with granary and tube well (2002 photo courtesy: M Bharati)

Plate 6.7c Settlement sited on the highest part of the sand bars. Inundation susceptibility reflected in the structure of individual buildings (2008 photo courtesy: Bileswar)

Plate 6.8a Multiple cropping at Bara Mana (2000 photo courtesy: Bileswar)

Plate 6.8b Intensive multiple cropping in the remaining agricultural plots (2002 photo courtesy: M Bharati)

Plate 6.8c Irrigation facilities at Bara Mana (2008 photo courtesy: Bileswar)

Plate 6.8d Intensive multiple cropping with irrigation facilities at Bara Mana (2002 photo courtesy: M. Bharati)

Plate 6.9 (**a**) and (**b**) Floriculture at Bara Mana (2008 photo courtesy: Bileswar)

Plate 6.10 Scoured river-bed used for household utilization and pisci culture (1997 photo courtesy: Durba Bhattacharyya)

Plate 6.11a Irrigation from shallow tube well at Rangamatia Mana (2000 photo courtesy: Bileswar)

Plate 6.11b Temple at Rangamatia Mana (2000 photo courtesy: Bileswar)

Plate 6.12 Riverbed sand quarrying from a boat at Majher Mana (1997 photo courtesy: Samir Ghosh)

Plate 6.13 Cattle shed at Gaitanpur (2008 photo courtesy: Durba Battacharyya)

Plate 6.14 Shallow thalweg and cultivated fields on the Amta channel bed (1997 photo courtesy: Samapti Dhara)

Plate 6.15a Brick kiln along Amta channel (1997 photo courtesy: Samapti Dhara)

Plate 6.15b Tile manufacture in marginal bar – Amta channel (1997 photo courtesy: Samapti Dhara)

Plate 6.16 Betel leaf plantation on riverbed of Amta channel (1997 photo courtesy: Samapti Dhara)

Plate 6.17 Land use in the Amta Channel (1997 photo courtesy: Samapti Dhara)

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