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).

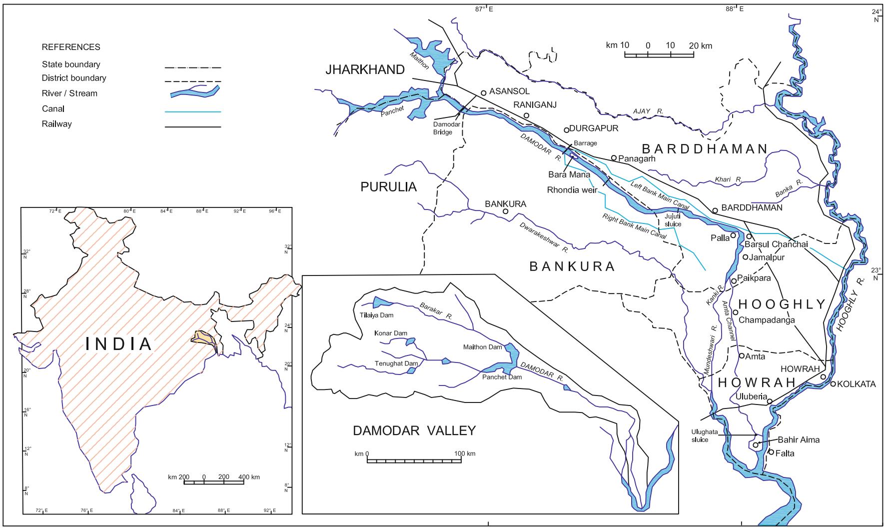

Fig. 2.1 Location of study area

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).

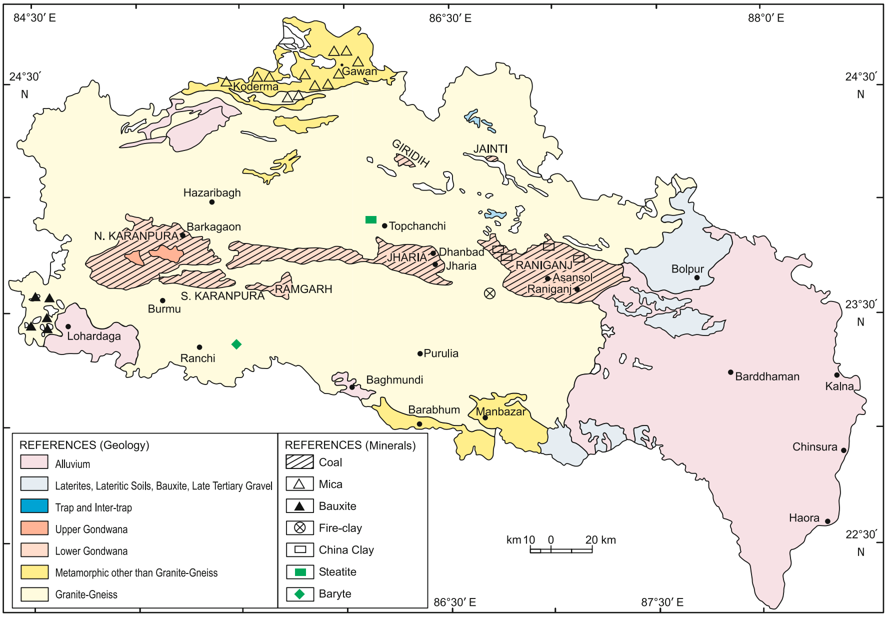

Fig. 2.2 Geology of Damodar valley region. Source: Chatterjee (1969)

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.

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

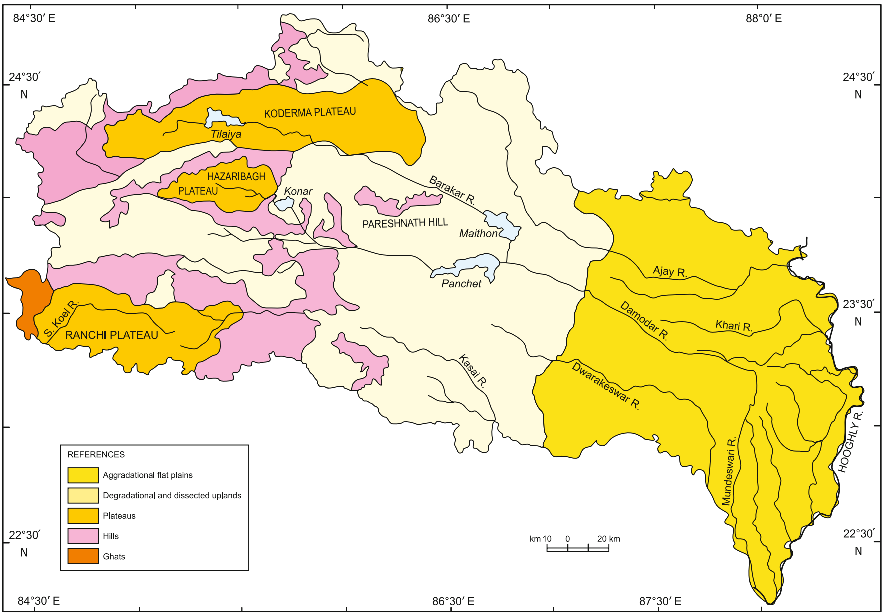

Fig. 2.3 Physiography of Damodar valley region. Source: Chatterjee (1969)

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;

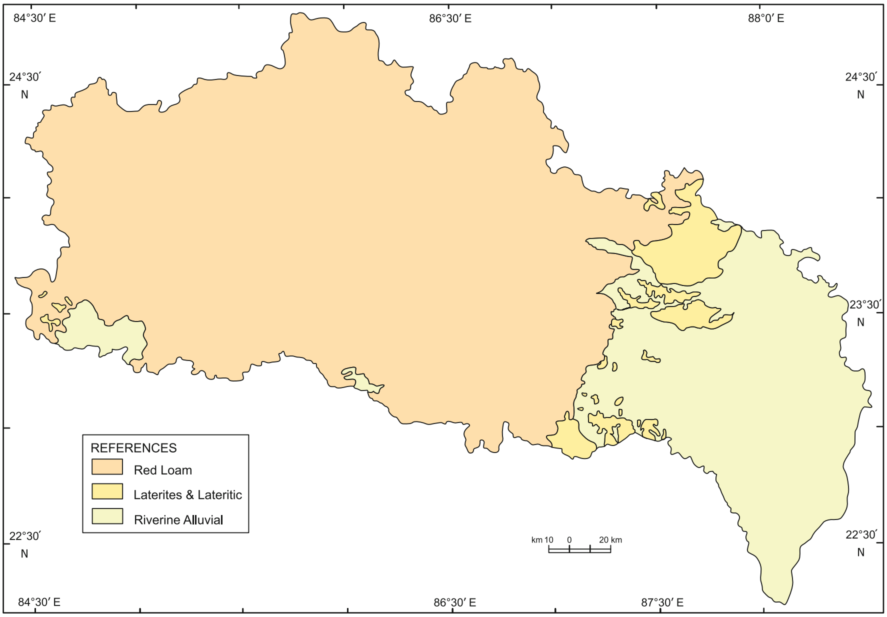

Fig. 2.4 Soil map of Damodar valley region. Source: Chatterjee (1969)

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.

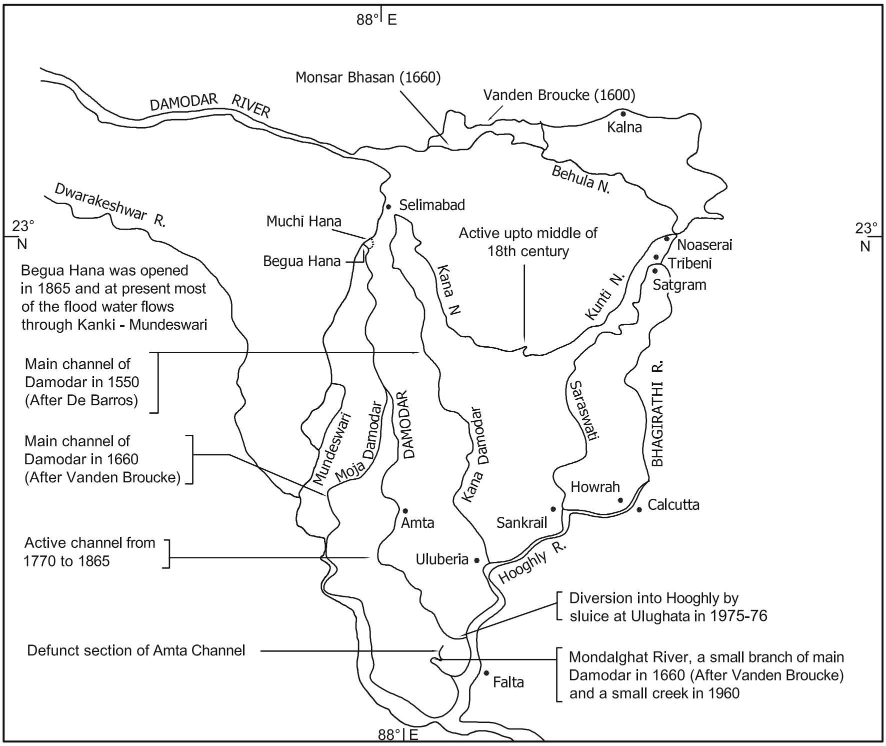

Fig. 2.5 Changing courses of Lower Damodar. (after Sen 1962; Basu 1889; Bhattacharyya 1998, 2002)

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.

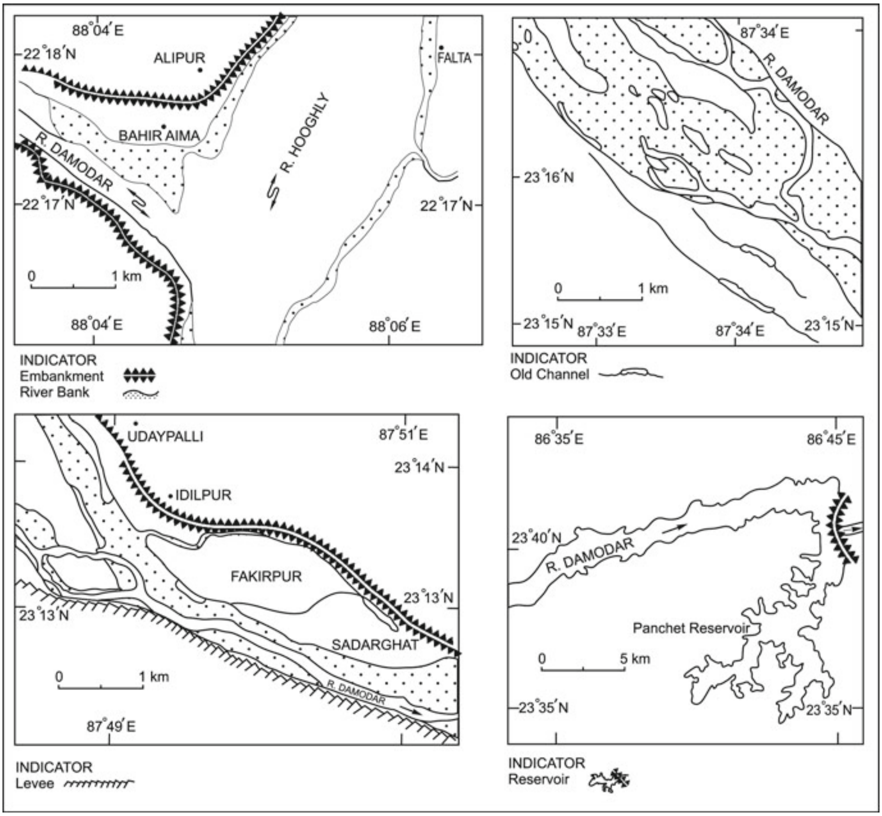

Fig. 2.6 Selected indicators for demarcating the study area

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 socio-economic 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

[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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