Chapter 5
The *Ganga* Morphology

The Himalayan ranges from where the Ganga and its northern tributaries originate, are still young and friable. Frequency of earthquakes owing to tectonic changes in the region and heavy rains in the catchments owing to elevation, spread and direction of the ranges obstructing the monsoon wind, cause frequent landslides and erode the soil. Variations of extreme temperature and the friable nature of the rocks enhance silt deposits. All these lead to high silt charge in the Ganga and its northern tributaries. As against this, non-Himalayan rivers, flowing south of the Ganga sub-basin originate at much lower heights and in lower rainfall zones. They drain the regions which are geologically more stable and carry much less silt and therefore, have a more stable course than the Himalayan rivers.

As stated, the Ganga takes its name not from the origin in Gomukh in the Himalayas but from Devaprayag where the Alakananda and the Bhagirathi join. Its source is at an elevation of 7,010 m, from where it flows nearly 280 km before descending on the plains at Rishikesh. Haridwar is 30 km downstream, from where it flows southward over a wide bed of boulders, with its volume of water much diminished when it enters the Upper Ganga Canal at Mayapur on the right bank in Saharanpur district. Southward, its bed becomes sandy, depositing alluvium on the banks. The Ganga flows shallow and unfit for navigation until it reaches Nangal in Bijnor district of UP, from where it takes a wide sweep first southwest and then straight south from Balawali rail bridge. Field observations revealed that the river's course in this zone shifted westward for about $1\frac{1}{2}$ km from its former course. For several kilometres beyond Daranagar village, the Ganga flows almost straight south; presently, it is moving eastward from the village, severely eroding the right bank (Fig. 5.1).

The river's morphology in this area is determined by the fluvial dynamics which sends a large volume of eroded material from the Himalayas to the flood plains. The deposits are generally made of fine sand, silt and clay. The braided pattern which starts right from Haridwar, is formed by alluvial deposits. Though braiding is the main feature in this zone, meanders also develop extensively along the course. Owing to braiding and meandering, the river's course oscillates from northwest to southeast and return with the alternate growth of alluvial fans in the river-bed. This oscillating course gives rise terraces, marshes, point-bar deposits too. The National Atlas Organisation reported in 1975 that from comparative study of aerial

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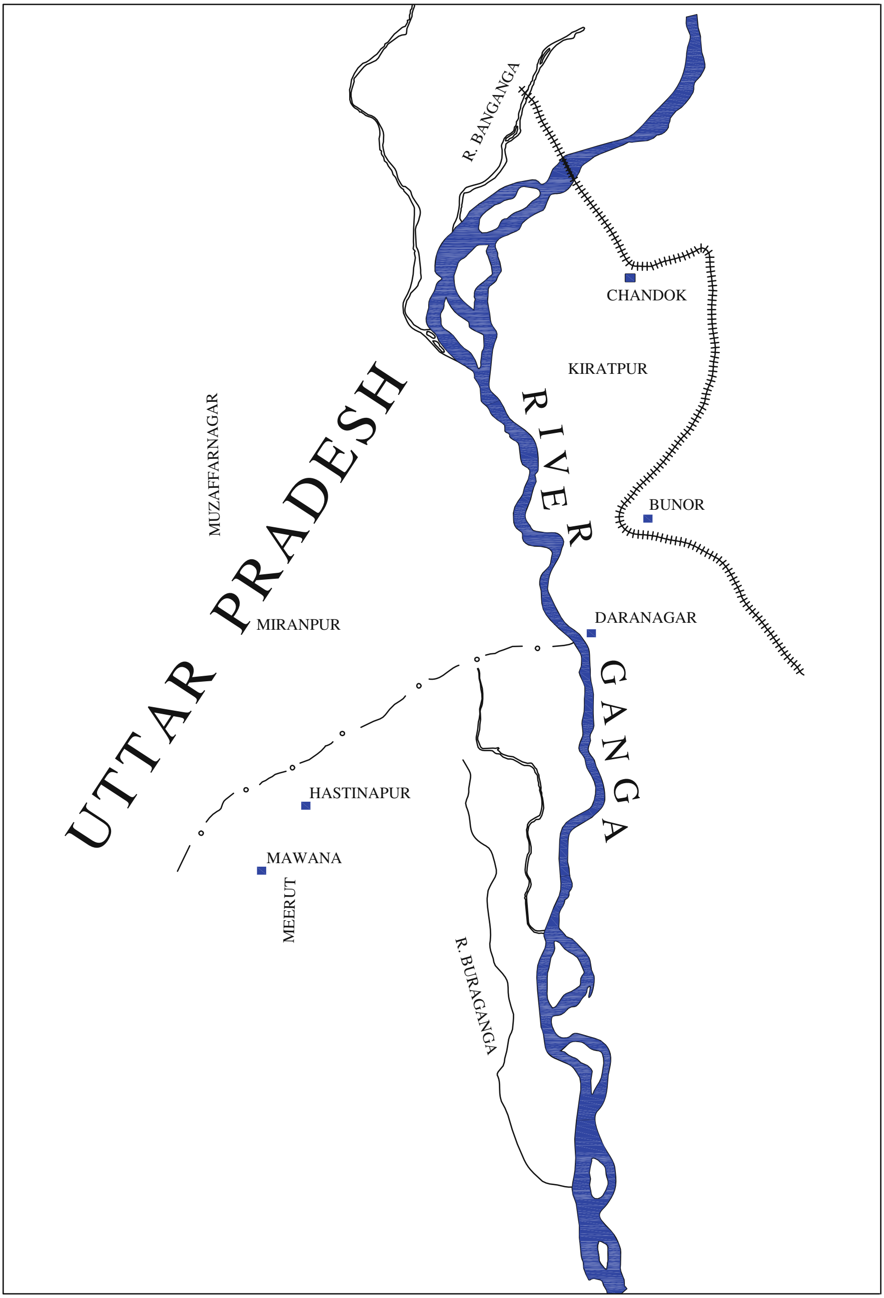


Fig. 5.1 Ganga in Uttar Pradesh

photography, taken in 1964 and the topographical map of the area surveyed in 1914, three positions of the Ganga were revealed in 50 years. The topographic survey indicated that the river shifted by about 6 km west of the previous course, which is now a deserted channel close to Bijnor terraces on the east. Aerial photographs in 1964 showed that the river had shifted further east by about 1 km from its course in 1914. The width of the flood-plain varies from 6 to 13 km in the north. Diversions in the course took place within this broad flood-plain. The last significant change in the main stream occurred after the 1953 flood, when it moved by some 2 km to the west to Shukartar, touching Hastinapur. Nowhere else the Ganga is so close to Hastinapur belt.

Alluvial terraces usually result from rejuvenation of a stream and consequent formation of steep-sided and flat surfaces above the bed. It may be brought about by increased gradient, either by tilting, or by increase in volume of water, or by decrease in silt-load. In this zone, the Ganga underwent several phases of change, filling its bed with sand-bars and islands, grown over with natural vegetation; this slowly diminished its discharging capacity. This may cause another diversion in near future, because if the Ganga cannot move further eastward, it is likely to move west, which seems to have already started. Its entire flood-plain belt is marked by low and elongated alluvial platforms, 2–6 m high, from the bed in dry season. Such platforms are typical alluvial terraces, made of sediments suspended in water after the flood recedes and deposits as levees on both banks, or as sand-bars in the river-bed. Eventually, these levees and bars rise above normal flood-limit and form flood-plain terraces which, in course of time, receive alluvium deposits, particularly during exceptional high floods.

The upper Ganga flood-plain is an elongated fluvial tract, stretching along both banks. Unlike adjoining old alluvium, the flood-plain has a more varied physical history and a different mode of human leaving. The Ganga's oscillating nature and its frequent high floods have lent dynamism to the natural and cultural landscape of the tract. The present form and trend of its regime are only a stage in its long and chequered history. The Burhiganga (literally,'Old Ganga') falls into it in numerous channels. The Ganga's recession was noticed by Taimur Long who invaded the region in 1398–1399 AD and mentioned in his mempor. Now a chain of swamps, the Burhiganga entered Meerut district of Uttar Pradesh from Muzaffarnagar, near Firozpur village and flowed southward to Garh Mukteswar where it joined the Ganga. According to the Mahabharata, Hastinapur, the capital of Kauravas, stood on the bank of the Ganga but no trace of it is seen now. It might have been washed away by the river in the beginning of the Kali Yuga (a Hindu Puranic aeon, corresponding to the Iron Age) over 3000 years ago, i.e., around 1000 BC. Taimur in his memoir mentioned Firozpur town as being on the right bank of the Ganga. Firozpur village near Ramraj on the right bank of the Burhiganga corresponds with Timur's Firozpur. If it is true, eastward recession of the Ganga from its old bed took place by about 10 km after 1400 AD. Over the ages, its course oscillated along the Burhiganga axis till about 1400 AD, after which it began to move eastward to its present course, past Daranagar village.

Floods are regular occurrence in this region, which peak in July and August but they do not make news, because other areas in the Ganga's flood-plain are affected simultaneously. Human habitation on this flood-plain, particularly in response to the hazard, has a lot in common with other parts of the country. Historically, the Gangetic plain has been a marginal preference for permanent human habitation. It was only a century ago that human habitation began in the flood-prone plains of the Ganga basin, which intensified after the Partition of the sub-continent in 1947 when hordes of displaced people migrated from Sind and western Punjab in Pakistan and settled in this region. The less densely populated flood-plains provided new sites for rehabilitation. Despite lack of experience in tackling occasional floods, the immigrants availed credit offered by the government and used modern techniques of farming commercial crops like sugarcane and wheat. The government gave land too to the refugees and helped them settle in unfamiliar and mostly flood-prone low land. For instance, the new Hastinapur town came up in this manner. The flood-plain hummed with noise of tractors, tilling the virgin land and new villages and growth centres emerged. Small-scale industries, like sugar and flour mills and petty engineering workshops also came up.

Thus in the upper catchment areas of the Ganga in parts of Uttarkashi, Chamoli, Pauri, Tehri, Dehradun and Almorah districts, many braided and meandering streams with swinging courses flowed into the Ganga. Soil erosion and gully formations took place in steep slopes. Deforestation and faulty farming caused frequent landslides. Mass rehabilitation encroached on the flood-basin and farming activities enhanced the silt-load, besides eroding banks, which in turn accelerated morphological changes in the river. The discharge suddenly increased below the confluence with Yamuna at Allahabad and caused more flood. Spills during high floods damaged the river and erosion increased near Varanasi, Balia, Mirzapur and Gaighat. Braiding and meandering also continued with the formation of alluvial fans, point-bars, swamps and marshy land, following deposition of alluvium, varying the river-width on the flood-plain from 5 to 15 km.

The Ganga enters Bihar near Buxar and after flowing about 450 km enters West Bengal near Maniharighat. On this long stretch, it also meandered and braided and the width on the flood-plain (*khadir*, in local parlance) goes up to about 15 km. Below Mokameh, it swung south from 1957 and eroded the south bank. Further down of Surajgarh, the river swung between Mungher and Mansi; it flowed in the vicinity of the former in 1936 but gradually moved north. By 1963, it eroded banks very fast, threatening the rail-line near Mansi. The peak discharge at Mokamah in 1969 was of the order of 73,620 cumecs. Spurs were put to shift the river southward and occupy the course it did in before 1936. Major sub-Himalayan tributaries, like Ghagra, Gandak and Kosi also brought huge quantities of silt, which changed braiding and meandering of the Ganga. It was observed that when the river went into high spate, the discharges from the tributaries were blocked, flooding the sub-basins and confluence points. This worsened when there was flood in the river and its tributaries, simultaneously (Fig. 5.2).

The Ganga's bank erosion in Bihar was primarily due to changes in the meandering courses. The stretch from Mokamah to Rajmahal was very badly erosive.

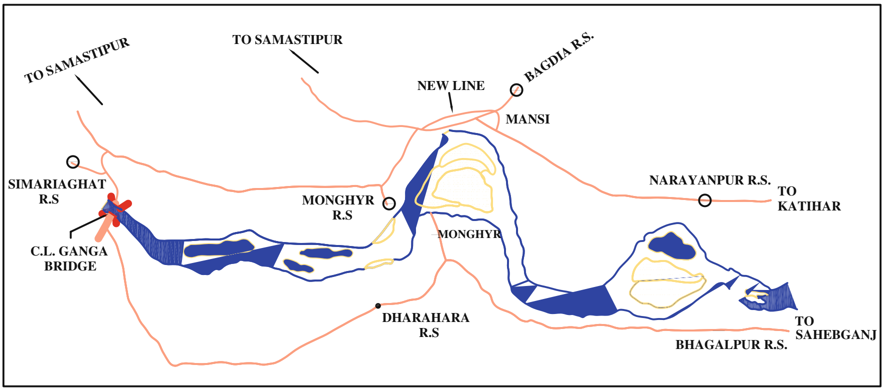


Fig. 5.2 Index plan showing Ganga river near Mansi railway station

Between Maniharighat and Rajmahal, the right bank is restricted by Rajmahal hill outcrops; the flood-plain spreads only on the left. The river swung southeast from near Rajmahal up to the confluence of Mora Kosi (dead Kosi) which joins the Fulahar near Bhutni Diara island in West Bengal on the left. It flows almost straight up to the confluence of the Fulahar, just below the island. Further down, it swung left at Manikchak in Maldah district of West Bengal and heavily eroded the left bank. Braiding and meandering continued and formed alluvial fans on the right. At some places, it has been bifurcated by point-bars in mid-stream, severely eroding the left bank. Erosion continued for about 35 km, from Manikchak to Farakka on the left, creating alluvial fans by soft deposits. Though the deep channel swings within the dominant waterway in the stretch, it is mostly located on the left side of the river and at some places, very close to the left bank which accelerates erosion. Alluvial fans continue on the right up to Farakka while the deep channel hugs the left bank (Fig. 5.3).

Human interference in any river, like navigation, transportation, irrigation, power generation, drinking water availability etc. has been the same in the Ganga too. The most important interference has been made at Farakka in West Bengal, where a barrage has been constructed mainly to partly divert its water to the Bhagirathi-Hooghly to rejuvenate it. Its benefits are being availed not only by India but by two Himalayan countries too – Nepal and Bhutan – but it has affected the morphology of the river, both up and down stream. It is very difficult for an alluvial river to remain both dynamic and stable and maintain its equilibrium in geological time. Such a stream retains this state if its discharge, sediment-load, size and bed slope are balanced. A change in any of these, or construction of a structure along, or across, is likely to disturb this equilibrium and aggrade, degrade or change its course. This continues for a long time till a new equilibrium is established. This is very important from engineering point of view too, as they both occupy considerable space and time. Owing to excessive aggradation, i.e., rise in the river-bed, the flood-level increases but the capacity of the channel decreases. Because of the latter, the channel

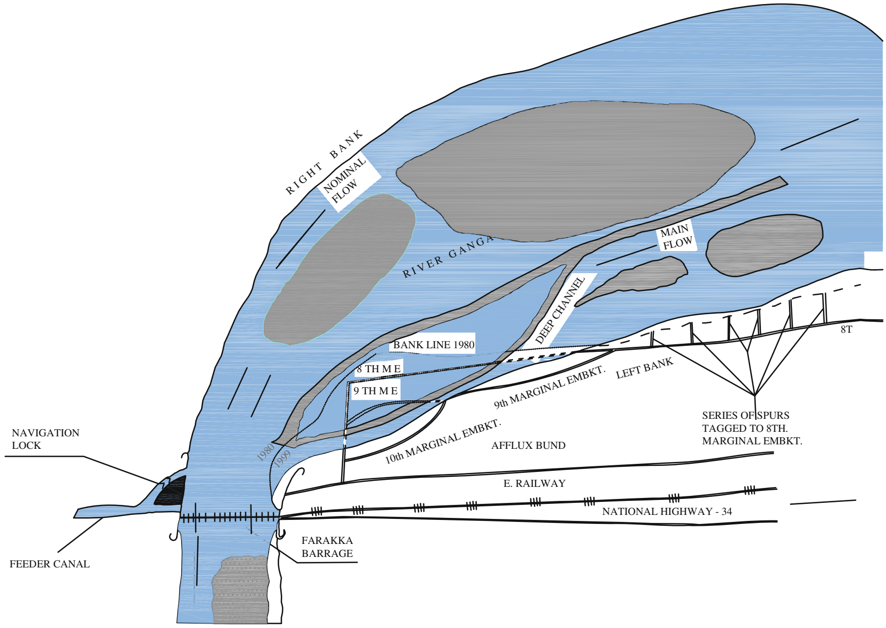


Fig. 5.3 River Ganga upstream of Farakka Barrage

cannot carry the required discharge in the present form and even at lower discharges causes flood. Otherwise, the channel will try to adjust its capacity by eroding the bed and the bank, if the materials are of friable nature. In an alluvial stream, the bed and the banks are normally made of materials which once got deposited during the change of courses, easing adjustment of their capacity. If the bed goes excessive low, it endangers structures on the bank, energy dissipation devices are affected and protection works and cut-offs downstream are disturbed, or damaged. Because of reduced depth of tail-water, the surrounding ground-water table also goes down which affects irrigation and drinking water supply downstream. However, aggradations and degradation give certain benefits too. The former raises the ground-water level which facilitates irrigation, drinking water-supply and navigation while the latter reduces flood hazard but their ill effects are severer than benefits. In both the cases erosion of bed and bank at some locations increase owing to reduced bed-gradient, inviting more concentration of the flowing water. A study of the Ganga's course revealed that it tends to both aggrade and degrade at many places.

The interference of the Ganga's regime by construction of the Farakka Barrage gave rise these problems and disadvantages. Changes in the water-level, discharge, sediment movement, bed-slope etc. caused aggradations and degradation of the bed and the entire reach from Rajmahal to Farakka in upstream and from Farakka to quite a distance downstream. Alluvial fans formed on the right side and the deep channel shifted to the left above the barrage. Bank erosion got worse, forming mobile and gradually-shifting point-bars at many places, mid-stream. The swinging river changed the channel by braiding and meandering, alternatively. One such point-bar developed upstream of the barrage on the right and is increasing in length, breadth and depth. This extension upstream is engulfing the mouth of the Feeder Canal at the Lock Channel entrance and causing the right channel shrink and stagnate as well as to erode the bank on the left. The growth of this bar left many long-term adverse effects and if unchecked along with other ill effects upstream of the barrage, may jeopardise its basic purpose. The morphological changes will continue to occur until the river adjusts to the changed conditions.

Downstream, on the left, there was a big alluvial fan which, moving up gradually before the construction of the Farakka Barrage, resulting flow concentration on the right and with the deep channel passing close to the right bank, eroded it. The fan extended up to about 30 km below Farakka; old Dhulian and Aurangabad towns on the right were also severely eroded. Moreover, the entire area was affected by occasional floods in monsoon months. After the barrage came up, the river-bed was degraded considerably and flood hazards reduced. The advance of the alluvial fan toward the barrage stopped. The left-side stream which existed before the barrage silted, leaving no trace of the channel. The fan is shrinking because of erosion of its right face, though reduced, following controlled discharge through the barrage, erosion has not stopped altogether and encroached land, necessitating very costly protective measures (Fig. 5.4).

Below Aurangabad – 20 km downstream – the river has two distinct channels, separated by a big point-bar, i.e., *char* land. Discharge through the right channel has reduced, giving more water way to the left which is very near Bangladesh border. There is very little habitation in the flood-plain, called *khadir*, in local parlance. The channel in the entire reach up to Jangipur, some 30 km, is mostly braided because of local meander zones up to the Bhagirathi off-take. The point-bars and alluvial fans are low and criss-crossed by channels which are all over-flooded in monsoon months. Erosion continues on both sides but as the left side is mostly *khadir* land and has little habitation, there is no hue and cry over this. The right bank which is thickly populated faced severe erosion in the 1970s, which afterward could be checked by protective measures (Fig. 5.5).

Below the off-take, the Bhagirathi flows for another 20 km into Indian territory and then along the border between the two countries for another 50 km or so. Here also, the river is predominantly braided with alluvial fans on the left and has low point-bars, intercepted by shallow channels owing to alluvium deposits. There were severe erosion on the right bank in the 1970s and 1980s; the right channel encroached on farm land and villages nearby. The erosion was checked for the first 15 km but further down, it is continuing. The most vulnerable reach where erosion is on is Akhriganj in Murshidabad where the densely populated area and the old town are affected occasionally. The left and right side channels have joined here, aggravating the situation. After flowing almost straight up to Lalgola, the river takes a left turn first and then a right turn above Akhriganj. The pattern changes from braided to meander before finally entering Bangladesh.

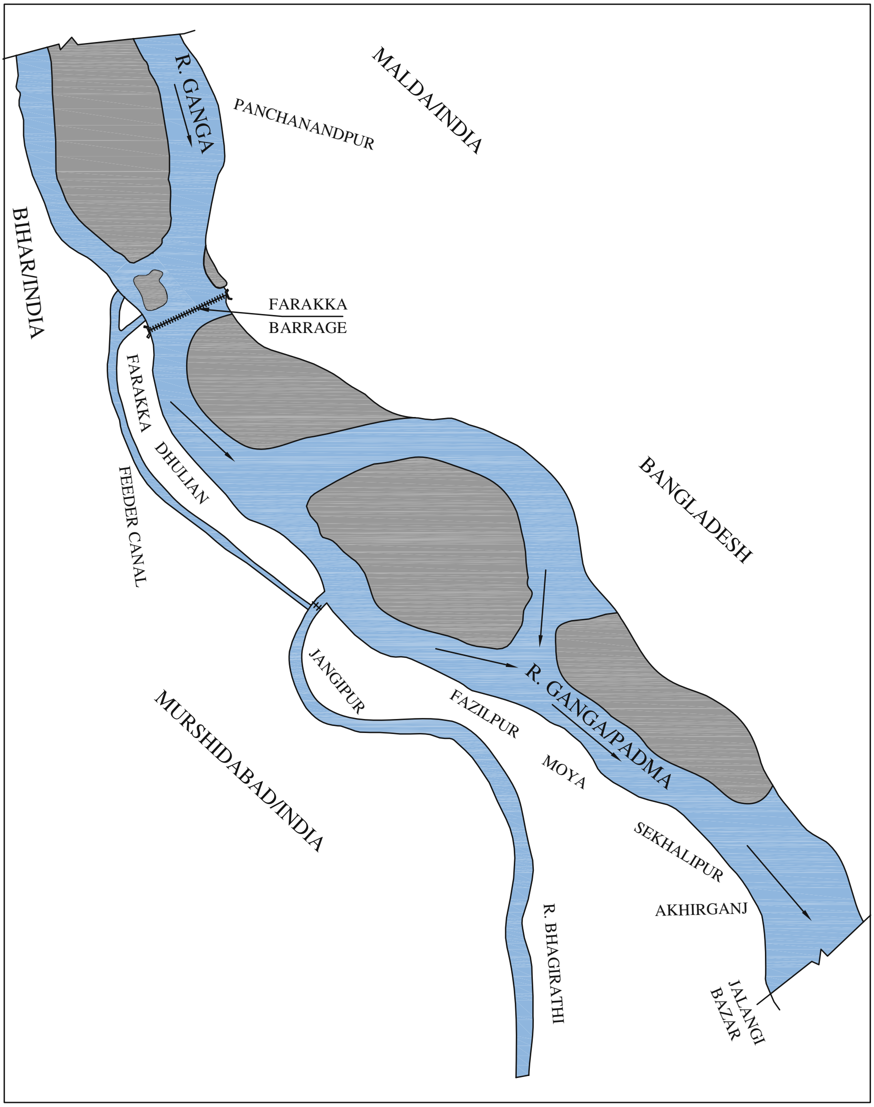


Fig. 5.4 Ganga/Padma river downstream of Farakka Barrage

The flow through the Bhagirathi is unidirectional toward the Hooghly (below Nabadweep) and the water-level rises between July and October but falls in the dry season from November to June. In its 230-km length, the Bhagirathi is fed by a number of major and minor tributaries from both sides – the major being the Bansloi, the Pagla, the Babla, and the Ajay on the right and the Jalangi on the left. All these except the Jalangi are ephemeral and bring sediment in monsoon season only. Before construction of the Farakka Barrage, the flow in the Bhagirathi was

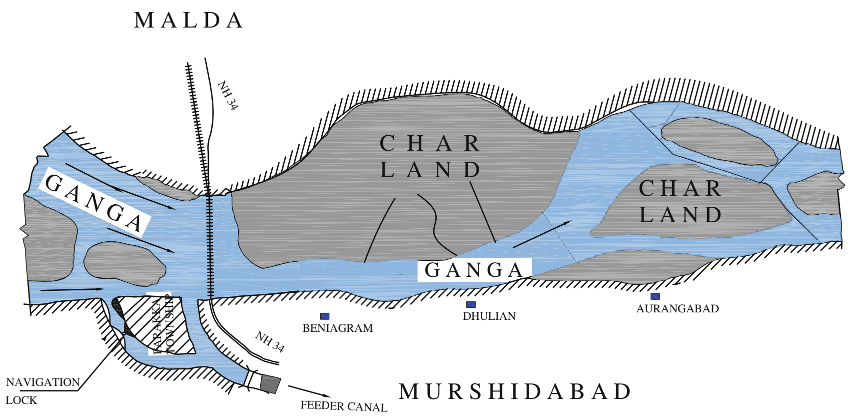


Fig. 5.5 River Ganga downstream of Farakka

very irregular; it used to be quite high in August and September but nominal, or nil, during rest of the year.

The Hooghly's flow is oscillating; the water-level fluctuates twice a day, owing to the tides and changes its hydro-morphology. Its estuary below Diamond Harbour being funnel-shaped, it restricts the optimum tidal influx which primarily governs the channel regime and its navigability. Before induction of the upland discharge from Farakka, the flow pushed the sand further up and made the river shallower. The induction of upland flow has reduced the sand movement considerably, degrading the river-bed.

In the pre-Farakka era, before the induction of upland discharge, the Bhagirathi-Hooghly reached a moribund state in its upper reach and a mature state in the middle reach from Nabadweep to Kolkata. However, the lower reach, south of Kolkata, remained active under tidal influence. Its cubic capacity decreased owing to deposition of silt and sand at the mouth and bed. After a barrage came up at Farakka, a discharge of 1,132 cumecs, or 40,000 cusecs, flows into the river in most part of the year, restrictions are imposed for the dry season, i.e., from January to May, when the discharge through the Feeder Canal reduced considerably, substantially improving the overall performance of the river. The bed started degrading and channel parameters, like width, hydraulic mean depth, cross-sectional area and the cubic capacity of the river increased. The moribund stage of the pre-Farakka condition gave way to the active stage in post-Farakka period.

An analysis of the channel pattern shows numerous meander stretches, separated by braids and also straight reaches at some places. There are four prominent braided reaches in the entire 450 km course of the river from Jangipur to Diamond Harbour, namely, the outfall to Raghunathpur (3 km), Chowrigachha to Suti (3 km), Katwa to Baladanga (12 km) and Zirat to Bansberia (3 km) – all north of Kolkata. In three braided reaches, the course is divided by the point-bars in mid-stream. There are many channels in Katwa-Baladanga reach where point-bars are intercepted by cross-channels. The river has a number of apparently straight reaches, uniting either a braided or a meander reach at the ends. Though these reaches have straight channels between high banks, especially at bankful stages, the thalweg of the reaches are actually wandering between the banks. The total length of the straight reaches may be about 140 km. Three major and lengthy reaches are from Murshidabad to Sonagai in the Bhagirathi and from Serampore to Garden Reach and Hooghly Point to Diamond Harbour in the Hooghly river.

An important feature of straight reaches is that the river is confined to the high banks in the same width and depth over a long period, while in braided reaches the parameters changed widely in different years. Unlike in braided reaches, the deposits on the bank are mostly of clay and silty clay in straight reaches, in which many alluvial fans form on both sides. Erosion of banks in these reaches is also less and spill-over in monsoon months are not common in straight reaches as in braided or meander reaches of the Bhagirathi-Hooghly. Meander reaches abound in the river, running to about 290 km. The bed-slope of these reaches is generally less than those of braided or straight reaches, adjoining them. Extensive erosion occurs in meander reaches as the banks are mostly made of silty fine sand, silty clay or clayey silt deposits. In many of such reaches, their length is much less than that of the straight length, raising tortuosity ratio. A 1986 survey showed that out of 59 meander loops, the ratio exceeded two in seven cases – six in the Bhagirathi and one in the Hooghly, all forming acute bends. In the Bhagirathi, the loops near Diara Balagachhi and Char-Chakundi in Murshidabad and near Purbasthali in Burdwan have very high tortuosity ratio – from four to five; in these two ends of the loops they try to join, forming cut-offs. In fact, two cut-offs occurred – one in Baidyanathpur in Murshidabad, at about 95 km downstream in 1984 and the other in Purbasthali at about 210 km downstream of the Bhagirathi off-take in 1990. The tortuosity ratio in both exceeded four, but in some places in spite of that there has not been any cut-off, owing perhaps to more erosive resistance of the bank materials.

The 1986 survey maps of the Bhagirathi-Hooghly showed that about 73% of the Bhagirathi's total length is meandering, 19% straight and 8% braided. The Hooghly meanders for about 56% of its length; it flows straight for about 43% and braids for only 1%. Of the total length, the joint river meanders for 64%, goes straight for about 31% and braids for only 5%. Thus, over all, the Bhagirathi-Hooghly is predominantly a meandering river.

Bank Erosion and Flood Control

Floods in the Ganga in Uttar Pradesh occur in areas below its confluence with the Yamuna at Allahabad. Downstream, its spills cause considerable damage during high floods. In Bihar, where high flood synchronises with high discharges of its tributaries, the river mouths are blocked by very high water-levels, causing widespread flood in the sub-basins. The main Ganga from Rajmahal to Lalgolaghat goes into occasional spates in vast areas, due mainly to drainage congestion and flood occurring at the same time in the Ganga and its tributaries like the Ghagra, the Gandak, the Kosi and the Mahananda, in which it is very severe. The September

1995 in Malda and West Dinajpur districts of West Bengal owing to flood-locking in the Mahananda after heavy and widespread rainfall caused heavy damages. The Yamuna, the Ganga's major right-bank tributary, threatened capital Delhi and inundated large areas in Haryana and Uttar Pradesh. Among right-bank tributaries, the rivers in the lowermost reaches, e.g., Mayurakshi, the Ajay and the Damodar inundate and cause acute drainage congestion. Called 'the Sorrow of Bengal' before a number of dams and reservoirs were built on it and its tributaries the Damodar used to flood south Bengal almost every year in the 1940s and 1950s; the Kangsavati, the Rupnarayan and the Haldi did the same, simultaneously.

The important among flood-control measures, taken in the Ganga sub-basin, include dams and storage reservoirs, barrages and marginal embankments, or flood-levees, as they are called. While the reservoirs are many, embankments running to over 5,000 km have been constructed along the banks of the Ganga and its tributaries. These are not very high and were built above the levels of dominant discharge of the rivers, leaving a sufficient margin beyond the water-edge. Embankments normally prevent high floods in the basin; some of these have falling aprons and protective slopes to control erosion and rotational slips during rains. Roads over these facilitate inspection and public use in monsoon months. Ill effects of jacketing a river by embankments are well-known; they aggrade river-beds, reduce bed-slopes and raising water-level, create further flood hazards.

Sir William Wilcock, a British irrigation engineer, who visited India in 1930, observed that embankments on the deltaic tributaries brought about adverse changes in their condition. He attributed changes in the courses of the Ganga's big torrential tributaries not to natural forces but to jacketing them by embankments. He added that if the spill was not restricted by artificial constructions, it would spread all over the land and leave very little silt on their beds. In such cases, the adjoining land would not rise beyond a foot in 100 years. With this, the river-bed would rise and no river would die. Very often, he said, engineers by obstructing the spread a spill, accelerated silt deposition in its own bed, or on its immediate surrounding and thus killed rivers.

Embankments, or levees, have been constructed on all rivers to control flood since ages, throwing up widely different views on their effect on the stability of rivers. One view is that rivers carrying high silt charge tend to lay their beds after construction of embankments; so they are to be periodically raised to control rising flood-levels. Therefore, they can help prevent floods in regions where the silt charge of the river is not too high, as in the Mahananda, the Godavari and the Krishna but on streams like the Yellow River of China, the Kangsavati in West Bengal, flood embankments have raised river-beds. Their heights are raised from time to time and the process goes on. This is the view of two Indian experts – S. L. Kumar and Kanwar Sain – but another expert, S. V. Chitale held that embankments enhanced a river's sediment-carrying capacity by augmenting discharge and hence did not aggrade it. If they are constructed with wide spacing in between, along an aggrading river, any increase in sediment transportation cannot stop aggradations and bed-levels would continue to rise; this cannot be due to embankments. He also held that tidal rivers have an inherent tendency to aggrade and hence embankments cannot arrest it but here again the rising beds are not due to embankments.

These are the adverse effects, caused by structures along, or across, the rivers – barrages, dams, bridges etc. Generally, upstream of a barrage, a river aggrades and downstream, it degrades but up to some distance, depending on the location of the barrage site. The erosive tendency also changes after a barrage or a bridge comes up. For instance, erosion of the right bank of the Ganga below Mokama developed only after the construction of a bridge near it. The barrage at Farakka did the same and changed the erosive pattern of the banks, both below and above it.

Bank erosion is associated sometimes with floods, particularly in alluvial rivers and in unstable reaches in the sub-mountainous regions. Meandering of the Ganga and of its tributaries changed their courses. When it did, it caused erosion in Uttar Pradesh, Bihar, Jharkhand and West Bengal. It is markedly prominent in the reach below Allahabad, from Mokama to Mansi to Narayanpur, from Manikchak to Farakka to Aurangabad, from Lalgola to Akhriganj, from Purbasthali to Nabadweep, from Howrah to Sankrail and from Diamond Harbour to Kulpi in West Bengal. Erosion is acute in the reach between Mokama and Mansi.

The Ganga has a meandering-cum-braiding pattern in this reach for a length of 85 km in 1780 to 110 km in 1965. The active channel has been swinging over a width of about 15 km, where alternate deep channels and alluvial fans formed. Below Mokama the river swung southward in 1957 and eroded the south bank. Below Surajgarh, it has been swinging between Mungher and Mansi; it flowed near Mungher in 1936 but started moving north and by 1963, eroded the bank near the rail tracks off Mansi station, to as high as 7.6 m, or 25 feet every day in rainy months and threatened roads and rail-lines. The meanders are never static but move downstream and cause cyclic changes once in 70 years or so, here and in other places on the course too. In such a meandering river, efforts to prevent erosion by drastic measures like long spurs obstruct the movement of meanders. The river would either damage the spur heavily, or other repercussions would follow at either above or below the spot which can cause sudden and considerable changes in the course by avulsions and cut-offs. It was, therefore, decided to give local protection by short spurs. A new technique of constructing spurs in large stone crates on the eroded bank was rather successful.

Further below Mansi, up to Narayanpur, severe erosion in 1973 threatened the National Highway No. 3 and the rail-line (see Fig. 5.2) and affected nearby villages. Simultaneously, the right bank also eroded too, below Mokama Bridge, near Berhaiya and engulfed some villages and farmlands. A cut-off occurred in the reach in 1965, reducing the river length from 17 to 9.70 km. In 1975 flood, the left bank from Ganaul to Narayanpur rail station was heavily eroded. It was observed that erosion here was by 119 m in 1962 and 1963. It increased to about 207 m, every year, between 1969 and 1975. Before the 1976 floods, the river's edge was about 750 m from the rail track and despite protective measures, it came closer to the line by about 460 m after the flood. As recommended by the high-level Tripathi Committee (1974) and the Ganga Erosion Committee (1977), spurs, bank revetment, bed bars, tagging embankments etc. were constructed, which checked erosion and diverted the main river to the right.

The left bank between Manikchak and Farakka in Malda district also experiences severe erosion. Before the barrage came up, the river upstream was straight and a big alluvial fan and a *char* land existed at about 20 km above. The downstream *char* land, which is now very near the barrage, was about 5 km away. This is shown in Fig. 5.4.

Survey data of 1939 and topo sheets of 1924 revealed that the river was meandering between Rajmahal and Lalgola. The 35.0 km course between Rajmahal and Farakka had two meander bends – one in its upper half and the other in the lower half, both on the right. The reach between Farakka and Dhulian, some 25 km, had one meander bend, leaving the main channel on the left. Similar alternate meander bends were seen even below Dhulian up to Lalgola and further down. The meandering pattern in 1939 indicated that below Farakka, the river would flow on the left as long as the main channel remained on the right, above Farakka. This was seen to have reversed in 1948–1949 survey maps, i.e., the main channel above Farakka flowed on the left and below it up to Dhulian, it flowed on the right. In 1956 survey, the river was seen to have reversed to the 1939 pattern (Figs. 5.6 and 5.7).

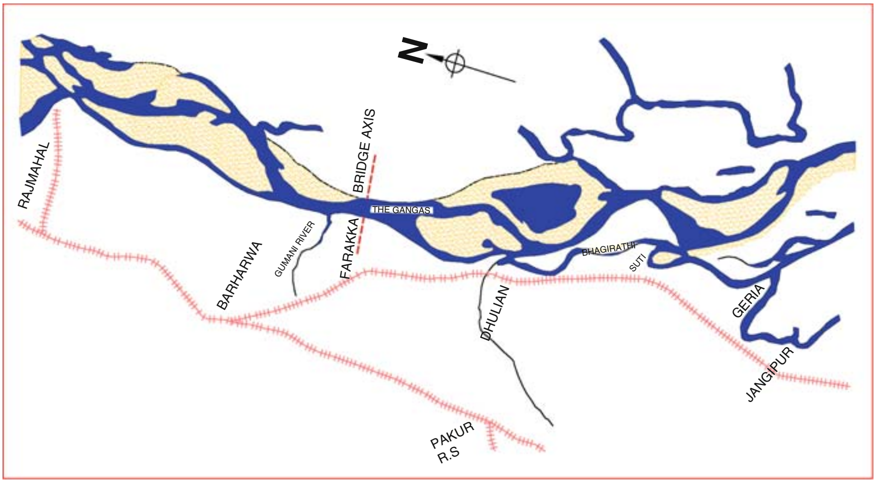


Fig. 5.6 Plan of the river Ganga showing 1939 course

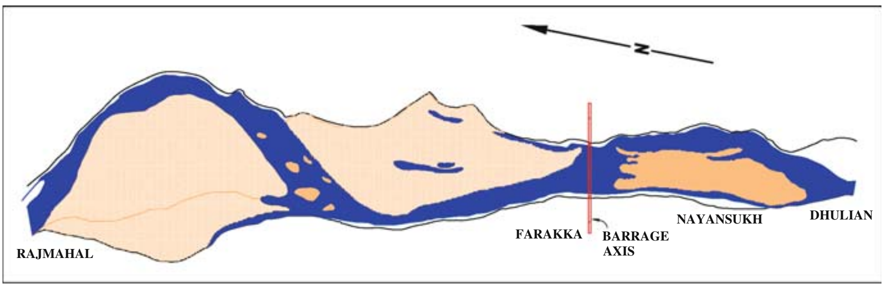


Fig. 5.7 Ganga river course around Farakka in 1956

The 1961–1962 survey did not show much change from the 1956 one in the meandering pattern. The channel was hugging the right bank up to 1.5 km above the barrage and thereafter it swung to the left. In fact, at the barrage site, it was about a kilometre away from the right bank. To avoid construction hazard at the earlier location, about 1.5 km upstream, the present site was chosen, which indicated that the river was swinging leftward, above Farakka, returning to the 1948–1949 course but the construction of the barrage at that location might have prevented such a shift.

The barrage was constructed in 1975 over the Ganga – probably the largest such in the world over the alluvial bed – by blocking the river in such a manner that Nature took time to adjust. Before it, it had two meander bends between Rajmahal and Farakka, One was intercepted by the barrage, to which the river adjusted. The latest survey of 1993–1994 revealed that the Ganga had combined two meander bends into one, from Rajmahal to Farakka, by keeping the deep channel on its left bank on Malda side, by eroding the left bank. The reach near Manikchak and the one from Panchanandapur to Farakka were severely affected for the last 20 years. The marginal embankment near Toffi village at about 7 km above breached in 1980 and despite constructing several spurs and strengthening them by stone apron and side-pitching with boulders in crates, the erosion was minimised but could not be wholly stopped. It shifted downstream and the embankment near Simultala village, at about 3 km above the barrage, was severely affected by breach in embankment in 1987. It breached nine times thereafter and gradually shifted toward the land, year after year. The areas are inundated quite often and farmland and villages submerged. Three to five kilometre wide and 5–7 km long land has so far gone into the river. On the right bank, a big alluvial fan has formed and is increasing day by day. A point-bar (*char* land) has recently come up toward the right, just above the barrage and is shrinking the right channel, which some day will jeopardise the operation and maintenance of the barrage. Experts say, this is natural for an alluvial river but would not have occurred if there was no barrage and adequate protective measures were taken upstream along with this human interference by spending a little. They were not taken because of callousness, ignorance and negligence of the government which now spends a fortune without much benefit. Photograph 5.1 shows the type of bank erosion near Panchanandapur on left bank in Malda district.

The banks near Manikchak and Gopalpur were also severely eroded. The marginal embankment and the protective measures taken in 1987 were damaged, causing widespread flood in the region. Erosion continued year after year, in various magnitudes up to 1999 and is likely to continue. Over a kilometre-wide land for about 5 km has been washed away. Owing to procrastination by the concerned government departments, protective measures of dubious value, as recommended by a model study in 1992 were not implemented until the monsoon of 1996. The measures included construction of two long spurs at Manikchak at 28 and 29 km above Farakka, to protrude deep by over 400 m to tag to the marginal embankment. These were to be made of crated stones, i.e., stones in a wire-net, over geo-textiles laid over the river-bed. This was postponed for various reasons.

Thus, the Ganga above the Farakka Barrage underwent morphological changes after it was constructed, which would continue to occur for some time yet to give

Photograph 5.1 Bank erosion near Panchnandapur in Malda district (See also Plate 1 on page 365 in the Colour Plate Section)

the river a dynamic stability. Any further interference by long spurs, diversion canals etc. may make the river swing leftward and aggravate erosion, which would require more time for the course to adjust to such changes and stabilise (Fig. 5.8). Photographs 5.2 and 5.3 show the breach of a portion of the marginal embankment and people taking shelter over the embankment.

As said, the 1960 survey showed the left channel as more active and larger than the right channel below Farakka. The right channel along Nayansukh village and Dhulian town was carrying less than 25% of the flood discharge in those days. It was observed that though the right channel was narrower than the left, the velocity of flood water in both was about 3 m/s and the channels were also quiet deep. This means, the erosion near Nayansukh and Dhulian could be due to the less active right channel because of increased flow in the narrower but deep secondary channel, a normal feature. The process continued for years and between 1945 and 1950, the river eroded about 1 km wide land near Dhulian town. In 1952–1953, erosion reached its zenith and old Dhulian town gave way. The 1939 survey surmised that the two bifurcated channels joined just below Dhulian town, where heavy flow concentration caused such devastation. The present Dhulian town came up at about 2 km downstream of the old town. Erosion lasted up to 1956 when the gap between the old and the new town also eroded so extensively from 1950 to 1960 that the old rail-line between Barharwa and Nimtita (to be precise, between Sankopara and Loharpur Halt) – a distance of about 13 km – had to be abandoned and a new line had to be laid away from the river-bank.

During the construction of the barrage, the earthen coffer dam, stretching from bay 1 to bay 52 on the right bank, was retained inside the river, from 1964 to 1969, although the sizes of the dam varied in different years. In the first year, the dam covered first three bays which were retained even in the flood season but in 1969

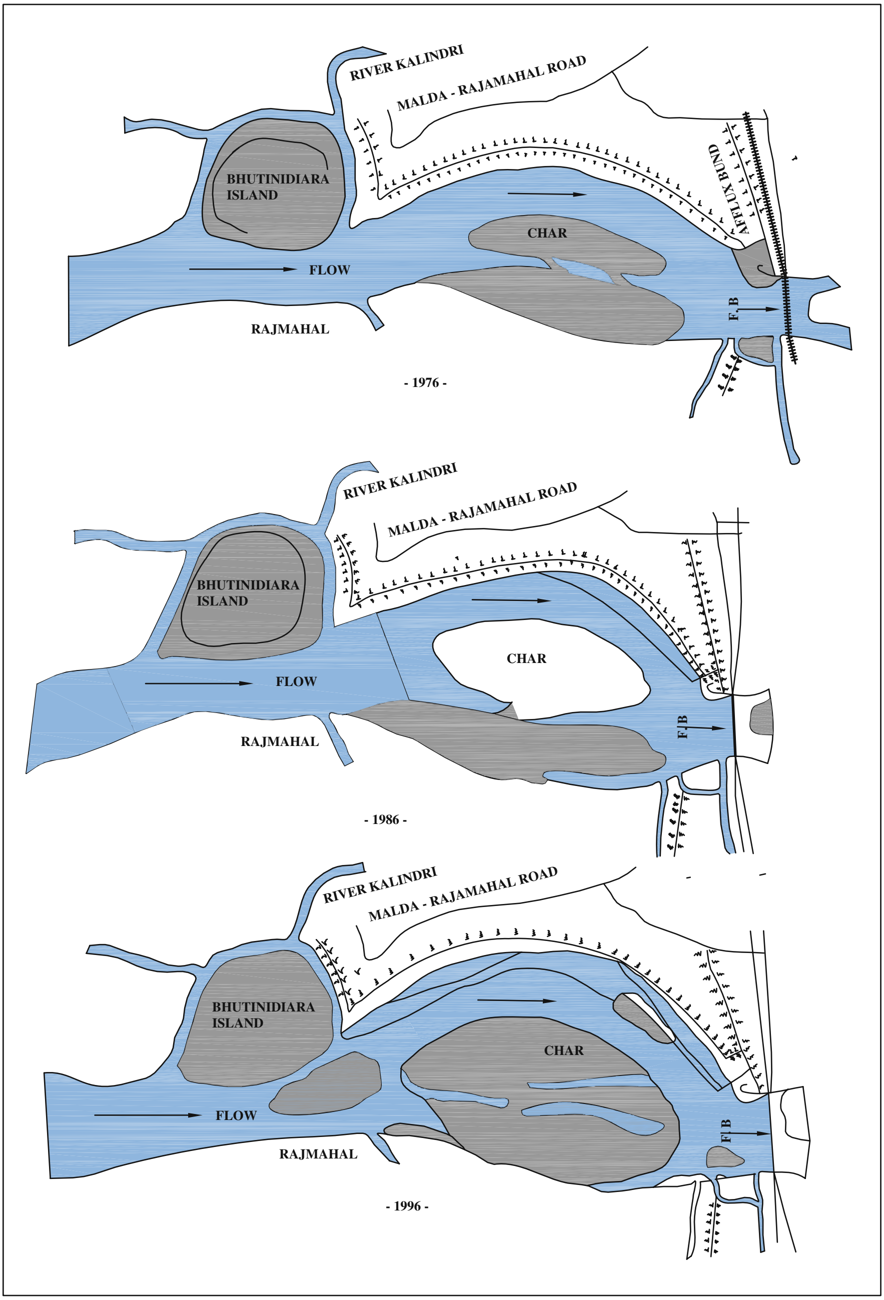
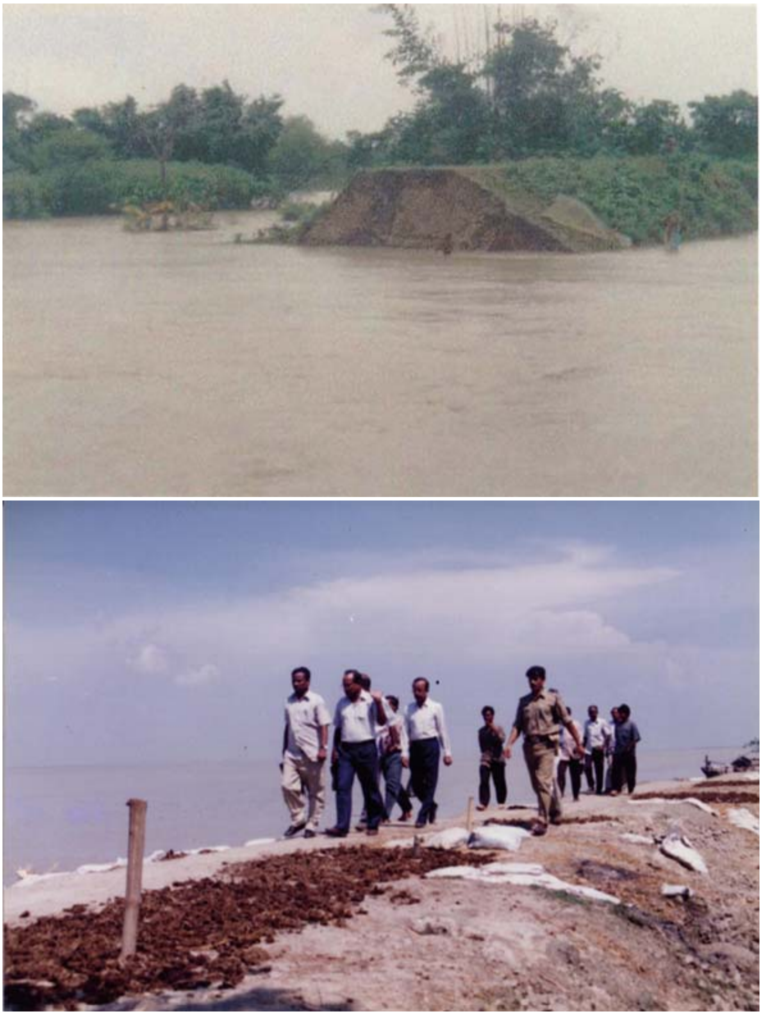


Fig. 5.8 Changes in river course between 1976 and 1996 on upstream of Farakka Barrage



Photograph 5.2 Breach of marginal embankment upstream of Farakka Barrage in Malda district during floods of 1998 (See also Plate 2 on page 366 in the Colour Plate Section)

monsoon season, the dam covering 52 bays was partly retained inside the river. Even with such obstruction, severe erosion threatened Aurangabad town below Dhulian in 1969. The right channel reportedly became very active and eroded the town by about 2 km in length and 150 m width in 1969 and took into it Suti police station. Since 1970, erosion near Dhulian and Aurangabad was checked by extensive protection measures and flow regulation through the right-bank bays of the barrage. Contour maps in 1971 indicated that the deep channel continued to remain on the left below the barrage. Although some left bank bays were throttled in 1970 and

Photograph 5.3 Flood affected people taking shelter over marginal embankment (See also Plate 3 on page 367 in the Colour Plate Section)

1971 floods, deep scours developed just below the closed bays, which meant that the main channel still remained on the left half of the barrage, downstream. These developments implied that the erosion of Dhulian and Aurangabad was not due to the construction of the barrage but to the joining of the two channels in the location, severely concentrating the flow.

Even before the formal opening of the barrage, in 1975, its gates were partly operated to regulate and pass the full flood discharge, downstream. The river's morphology began to change because of the barriers since 1970. The downstream shoal (alluvial fan) inside which was away from the barrage by about 2 km in 1960 moved toward it owing to the changed flow and silt deposition and finally reached within 500 m by 1980. The left active channel gradually shrank owing to the obstruction. The deep channel which was shifting leftward to the barrage with the flow stopped. The primary consideration for regulating the barrage gate was to keep the channel on the right, upstream so as to draw required silt-free water into the Feeder Canal. To achieve this, the right bays were kept open more during rising and falling floods. The cross current, or parallel flow, which developed in initial years of operation from right to left in front of the barrage was prevented by protecting scour holes and by constructing the submerged bed-bars at various bays, both below and above the barrage. Moreover, as the passage of water was blocked, the flow hit the land adjacent to the right guide bund and eroded it. The protective works of the bund were affected and had to be maintained at great cost. All these along with the throttling of the barrage gates, more on the left side, increased the siltation of the left channel below, which slowly dried up by 1983, or so and the mid-river *char* extended and joined the left bank. This way, the left channel below was completely blocked and local people started cultivating on it. It remained blocked, round the year, for over 2 km on the left and only a thin course flowed further down. It reduced the sudden flow concentration on the right bank, near Dhulian town which might have helped reduce the erosion near it and Aurangabad town afterward.

As the left channel was blocked, the flow enhanced on the right channel by creating cross, or parallel, flows downstream, from the left to the right, which created deep scour-holes in the bed and threatened to move toward the barrage. This was prevented by dumping stones etc. at a huge cost up to 1988, which stabilised the holes. The submerged bed-bars, constructed later, slowed down the formation of a cross-flow and pushed it to hit the *char* and arrested its advance toward the barrage. As a result, the flow got more passage below to join the right-side secondary channel. This eventually became the only channel below the barrage. Afterward for holding the entire flow, very high floods, above 50,000 cumecs occurred, completely submerging the *char* and distributing it over the entire width of the river. The huge concentration during both rising and falling floods started eroding the right bank, just below the barrage in villages like Beniagram, Bindugram, Jaffarganj, Nayansukh very critically from 1983, or so and orchards, mango groves, farmland etc were engulfed. Bank revetment and other protective measures were taken by the barrage authority and the State irrigation department at very high cost to control erosion up to Dhulian town but it was quite severe from 1984 to 1990 and again in 1995. Of the 20 km reach from Farakka to Dhulian about 10 km could be protected up to 1995 and erosion controlled. Work on the remaining portion was done in phases but about 150–300 m wide land was washed away.

Had the left channel been kept active after commissioning the barrage by properly regulating the barrage gates and artificial dredging, the flow could be maintained and erosion on the right bank minimised. The bed-bars below, at different bays required regular maintenance and extension. The deep channel is still very close to the right bank but meandered to the left, below Dhulian. It being almost straight up to Dhulian with a few local bends, it would not have been difficult to prevent, or reduce, serious erosion in this reach owing to excessive flow concentration and weak bank. Properly designed revetment by small bed-bars could hold the bank-line and keep the channel away from it. Any other technique for holding the bank-line, i.e. by long spurs might have helped divert the main flow toward the parent river but this would have definitely aggravate erosion, further down, at new Dhulian town, or below. The deep channel which shifted left, through another meander bend, would be disturbed because of upstream encroachment by spurs, making it shift to the right again, which would be disastrous and may restart erosion. The morphology of the alluvial channel which takes pretty long to attain dynamic stability would be disturbed again.

Other erosion zones further down, on the right bank, at Geria, just above the Bhagirathi offtake, Raghunathpur, Kutubpur etc. downstream, could be controlled by protective measures. Two channels united below Kutubpur and the combined discharge hugged the right bank, causing severe erosion. Farmland and villages were affected and very costly protective measures are now under way to protect them.

The meander bend on the right bank continued up to Akhriganj in Murshidabad before the river finally enters Bangladesh. This deep channel which is very active on the right bank caused severe erosion near Akhriganj and Jalangi *bazar* area for about 8 km since 1930, engulfing over 350 m wide land. In 1989 erosion here was more severe and a large landmass, including school, market and other buildings went into the river. Erosion continued up to 1995 and in spite of spending huge amounts by the State government to check erosion could not be totally stopped. Long spurs constructed in 1990 were severely outflanked. Erosion below the spurs increased, affecting civil structures and farm land.

The Bhagirathi-Hooghly became moribund in its upper reach in pre-barrage days. It used to be active only in monsoon months, when activities on it reduced and its silted mouth was over-flooded by the high Ganga level and again from October, or so, the flow decreased, rendering the river a stagnant pool. As there was practically no flow from November to June, there was no bank erosion in the upper reaches in those months except in monsoon months. Slips only occurred at some places owing to the drawdown state of the ground-water table. In the lower reach in the Bhagirathi and the Hooghly the condition was different, as it was a mature and active reach because of flows from the tributaries and the tides from the sea. Therefore, these reaches suffered bank erosion, round the year, which aggravated in monsoon months. After induction of upland discharge through the Feeder Canal, the joint river remains active throughout the year, regaining its life. This rejuvenation gave rise to erosion in many reaches, which is particularly severe in meander bends but less in braided and straight reaches. The most vulnerable erosion zones of the river, as revealed by the survey data of 1985–1986 are shown in Table 5.1.

The Table 5.1 shows that in 1985–1986, there were 26 major erosion-prone zones in the Bhagirathi-Hooghly. The first 16 were in the Bhagirathi and the last nine in the Hooghly. The approximate affected length and the nature of land loss are indicated in the table. Mostly farm land, villages and industries were affected. The total affected length on the left bank was about 40 km and about 45 km on the right bank, out of the total length of the joint river of 425 km from the offtake in Murshidabad to Falta in south 24-Parganas district. In many of these affected reaches, the river has been engulfing farm land, almost every year. The shift of bank line in four major reaches (two in each) – Purbasthali and Mayapur on left bank and Samudragarh and Zirat on right bank from 1976 to 1987 are shown in Table 5.2.

The continuous encroachment by the river on the land by the Mayapur reach from 1976 to 1987 is shown in Fig. 5.9 below. On the left bank stands the famous Vaishnaba temple and the headquarter of the ISCON and on the right the legendary Nabadweep town, abounding in Vaishnava temples and controversial birth place of Shri Chaitanya Dev, founder of the Hindu sect. It is also near the outfall of the Jalangi, a tributary of the Ganga. Over a million square metre of land went under water between 1976 and 1987; the old temple is now threatened. All the four reaches, as shown in Table 5.2, are within the meander loops. Erosion is severe on the concave side of the bend with alluvial fans formed on the opposite face. A study of erosion of the joint river in 1985–1986 showed that the annual erosion in the

Table 5.1 Vulnerable erosion zones of the Bhagirathi-Hooghly as per survey data of 1985–1986

Sl no	Location	Channel pattern	Distance from offtake (km)	Affected length L/Bank (km)	Affected length R/Bank (km)	Nature of land loss
1	2	3	4	5	6	7
1	Gobindapur	Meander	20.0	Nil	3.54	Agricultural land
2	Balagachi	Meander	47.0	Nil	3.93	Agricultural land
3	Baidyanathpur	Meander	96.0	1.05	1.05	Village
4	Chowrigacha	Meander	99.0	2.50	Nil	Village
5	Nagar	Meander	110.0	3.78	3.47	Village & agri Land
6	Ramnagar	Meander	132.0	Nil	2.83	Village & agri Land
7	Narayanpur	Meander	146.0	3.35	0.35	Village & agri Land
8	Katwa	Braided	157.0	0.36	3.20	Village
9	Kalikapur	Meander	168.0	Nil	3.14	Village
10	Charchakundi	Meander	174.0	6.45	5.69	Village & agri Land
11	Dampal	Meander	194.0	2.23	4.35	Village & agri Land
12	Bholadanga	Straight	203.0	Nil	2.05	Village & agri Land
13	Karkaria	Straight	209.0	4.23	Nil	Village & agri Land
14	Cutsali	Meander	220.0	3.04	5.03	Village & agri Land
15	Purbasthili	Meander	225.0	1.00	1.00	Village & agri Land
16	Mayapur	Meander	232.0	2.03	0.92	Do & temple
17	Satkhali	Meander	240.0	1.45	0.30	Agricultural land
18	Samudragarh	Meander	248.0	0.50	1.50	Do & office
19	Hatipota	Meander	255.0	0.70	0.60	-do-
20	Santipur	Meander	285.0	0.60	Nil	Village & agri Land
21	Fulia	Meander	293.0	2.10	0.20	Village & agri Land
22	Balagarh	Meander	300.0	0.20	0.50	Village & agri Land
23	Zirat	Braided	310.0	2.50	0.50	Village & agri Land
24	Sankrail	Meander	388.0	Nil	0.60	Industry
25	Falta	Straight	425.0	1.80	Nil	Industry
			Total	39.87 km	44.85 km	

Table 5.2 Migration of bankline in different meander loops of Bhagirathi-Hooghly between 1976 and 1987

Location and Bank	1976–1980 (m)	1980–1985 (m)	1985–1987 (m)	1976–1987 (m)	Total affected length (m)	Total land area lost between 1976–1987 (10^4 m^2)
1	2	3	4	5	6	7
Purbasthali (left-bank)	170	245	100	515	2080	107.10
Mayapur (left-bank)	144	256	104	504	2500	126.00
Samudragarh (right-bank)	45	30	45	120	800	9.60
Zirat (left-bank)	40	265	125	430	2500	107.50

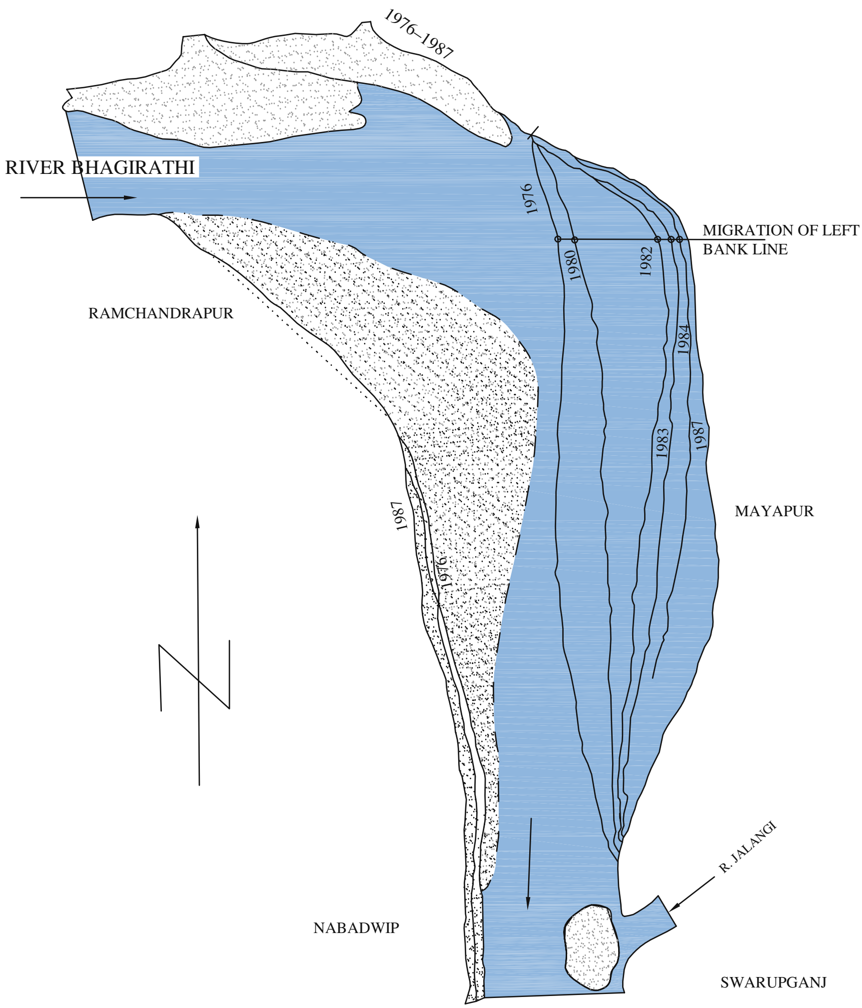


Fig. 5.9 Bankline migration near Mayapur reach

Bhagirathi alone is of the volume of about 8.5 million cubic metres and yearly land loss is about 220 hectares. It revealed that erosion in the Hooghly is much less than in the Bhagirathi, due probably to the presence of major towns and industries on both banks of the former and to protective measures taken by authorities to save their buildings etc. (Fig. 5.10). Photographs 5.4 and 5.5 show the type of bank erosion near village Palasi in Murshidabad district and Nayachara island in Hooghly estuary.

A noted village, Fazilpur, lies in the reach between the off-take point and Moya village where the distance between the Ganga and the Bhagirathi is the minimum, about 1.20 km only. In 1980, when the right channel was more active, severe erosion

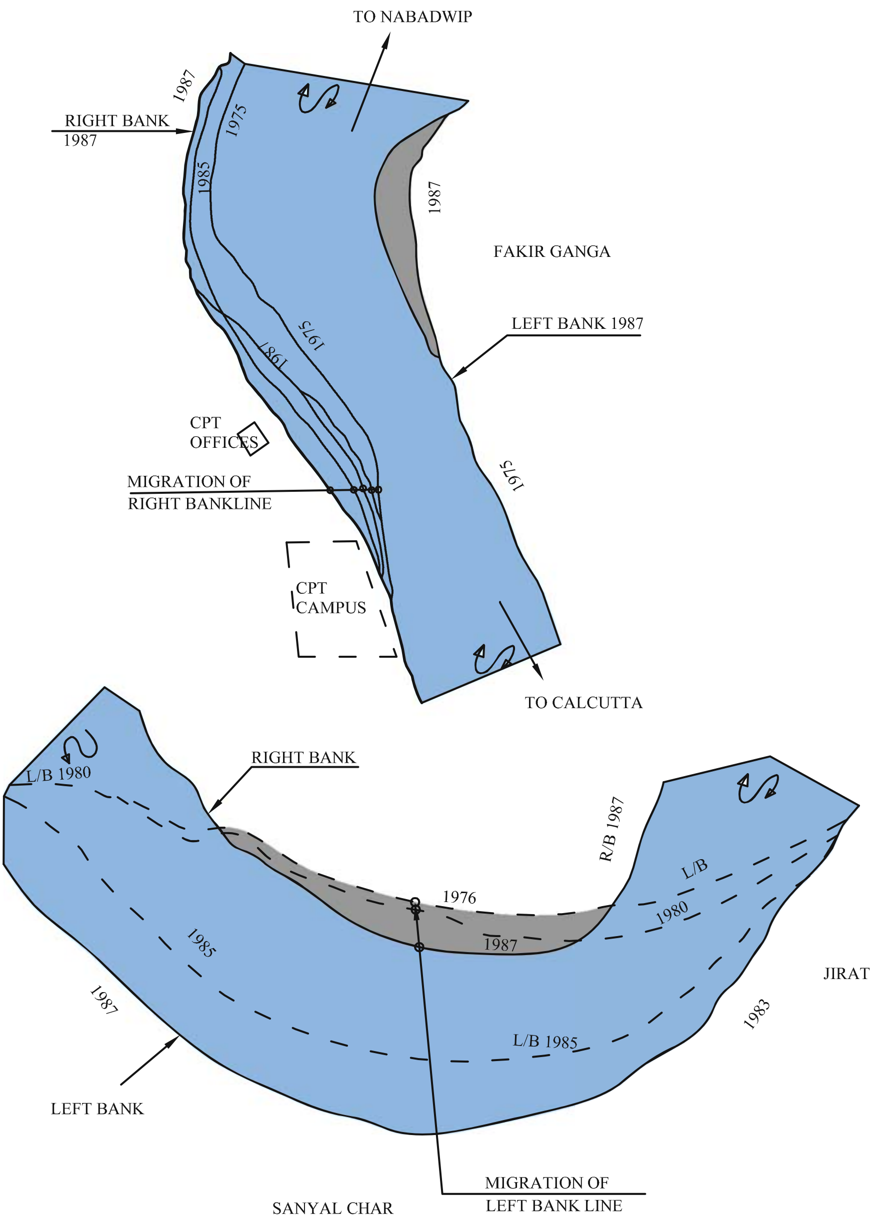


Fig. 5.10 Bank line migration near Jirat-Sanyalchar reach

occurred and a huge mass of land was engulfed. As a result, the distance between the rivers had been reducing gradually The position is shown in Fig. 5.4. Though the left afflux bund of Jangipur barrage and the Jangipur-Lalgola State highway are through this in-between land, there had been a lot of public criticism through the media

Photograph 5.4 Bank erosion of Bhagirathi near Palasi (See also Plate 4 on page 367 in the Colour Plate Section)

Photograph 5.5 Bank slip of Nayachara island near Haldia (See also Plate 5 on page 368 in the Colour Plate Section)

about the danger of joining the Ganga with the Bhagirathi at this place, because erosion would bring the two rivers closer and ultimately join them. If this occurs, the entire flood-water of the Ganga – about 2.7 million cusecs – would try to pass through the Bhagirathi, flood all south Bengal districts and Kolkata and would cause large-scale devastation. The Ganga bank was protected at this reach in early 1990 by armouring the slope and the bed with crated stone-boulders by the Farakka Barrage Authority, which arrested erosion. The zone has since silted up and the gap between the two rivers has been maintained at about 1.20 km for the last few years. Here the right channel has shrunk owing to siltation and the central *char* land has moved rightward.

Further down, the two channels have joined on the right side near village Moya forming a single one passing very close to the right side. The deepest channel is near the bank and the river has taken a concave shape. The afflux bund is very close and the frontage land between the bend and the bank has been eroding gradually. Before the flood season of 2000, a land width of about 120.0 m for a length of about 2.0 km has been washed out. The river is now flowing very close to the afflux bund and may breach the same in future by-passing the flood discharge of the Ganga towards the Bhagirathi and over-flooding the country side villages. Further down, the river has taken a sharp bend from right to left up to the village Sekhalipur with concave face on the right. Severe bank erosion has been occurring on the right. The river bank has been armoured heavily at the location by State Government and the bank has been acting like an armoured spur. The left side of the river is occupied by a big char land and the same is gradually advancing towards right and pushing the main channel further towards land.

Below Sekhalipur the deep channel flows on the right up to Jalangi Bazar, the last point of Indian territory before entering fully into Bangladesh after travelling a length of about 30 km. The place Akhriganj comes on the way which was affected by severe bank erosion since 1930. The efforts of the State Government to control erosion at this location have not been successful and the erosion process is continued. The river on the right side has entered Bangladesh in Kustia district in the name of the river Padma.