Indus-Ganga-Brahmaputra Plains: The Alluvial Landscape

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Abstract

The vast alluvial plains of the Indus-Ganga-Brahmaputra river systems form one of the three major geomorphic provinces of the landmass of the Indian subcontinent. Drained by these three large rivers, these plains show significant variations in terms of landform development due to significant hydrological differences and variable tectonic-geomorphic regimes of their hinterlands. These plains have accumulated several kilometers of alluvial sediments over Quaternary timescales and are underlain by Siwaliks or older basement. Distinctive river processes in these three basins have often resulted in severe fluvial hazards such as floods, bank erosion, and rapid migration affecting millions of people.

Keywords

Large rivers • Alluvial plains • Himalayan foreland • Geomorphic diversity • Fluvial hazards

1 Introduction

The Indus-Ganga–Brahmaputra (IGB) Plains form an integral part of one of the largest sediment routing systems of the globe (Fig. 1), the Himalayan-Bengal-Nicobar and the Indus submarine fan systems, which was initiated following the commencement of Himalayan orogenesis in the Eocene. The India-Eurasia collision led to a thickening of the crust in the Himalayan region, which in turn resulted in lithosphere flexure and the formation of a peripheral foreland basin that extends in the south along the length of the orogen. This foreland basin has acted as a depocenter through most of the Cenozoic and continues to receive detritus from the Himalayan as well as the cratonic highlands. The proximal part of the foreland has been deformed as a consequence of the southward migration of the Himalayan fold thrust belts, and forms the outermost part of the Himalaya. To the south of the sub-Himalaya, the foredeep is covered by vast alluvial plains that are drained by the Indus, Ganga and Brahmaputra Rivers (Table 1). Much of the sediment brought from the highlands is stored in these alluvial tracts in the sub-surface, and in places may attain thicknesses of several kilometers. At a synoptic scale, these plains have a low relief and are marked by the development of piedmont zones, channel belts, floodplains and large interfluves.

From the west to east, these plains are divisible into the Indus Plains, the Ganga Plains which are further divisible into an eastern Ganga Plain dominated by fan-interfan setting and a western Ganga Plain dominated by a valley-interfluve setting, and the Brahmaputra Plains which are characterized by large widths of channel belts and the development of large alluvial islands and wetlands.

The Indus-Ganga-Brahmaputra (IGB) Plains constitute one of the three major geomorphic provinces of the Indian subcontinent with the Himalaya occurring along the

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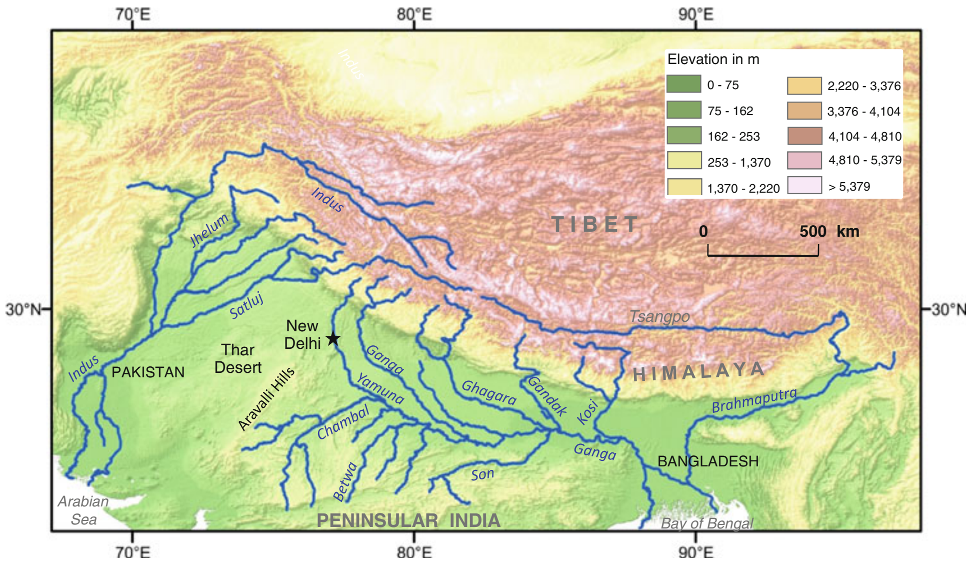

Fig. 1 Major drainage of the Indus, Ganga and Brahmaputra basins

Table 1 Drainage basin characteristics and hydrology of Indus, Ganga and Brahmaputra Rivers

Parameter	Indus	Ganga	Brahmaputra
Catchment area (10^3 km^2)	960	980	580
Total length (km)	3180	2150	2880
Average annual discharge (m^3/s)	7610	11,600	19,300
Annual sediment load at river mouth (million tonnes/year)	291	599	580–650
Unit discharge (10^3 m^3 s^{-1} km^{-2})	8	11.8	33.27
Sediment yield (million tonnes/km^2/year)	0.30	0.61	0.85–1.12
Contribution of snowmelt (%)	>50	22	<25
Major tributaries	Shyok, Shigar, Hunza and Gilgit, Jhelum, Chenab, Ravi, Beas and Satluj	*Himalayan*—Yamuna, Ramganga, Ghaghra, Gandak and Kosi *Cratonic*—Chambal, Sindh, Ken, Betwa, Son and Punpun	*Himalayan*—Dibang, Lohit, Jiadhal, Ranganadi, Puthimari, Pagladiy *North Bank*—Subansiri, Jia Bharali and Manas *South Bank*—Burhi Dihing, Dhansiri, Dikhow, Kopili, Kulsi and Krishnai

Source Goswami 1985; Hovius 1998

northern margin and the Indian Peninsula occurring to the south. These plains are richly endowed with surface and groundwater resources and fertile soils and form one of the important monsoon rainfed agricultural regions of the world supporting a population of >500 million, almost a third of the population of the subcontinent.

2 Geological Setting

The IGB Plains predominantly consist of alluvial and deltaic surfaces that are an integral part of the Himalayan foreland. The India-Eurasia collision led to the formation of NW-SE trending Himalayan Arc as well as the development of

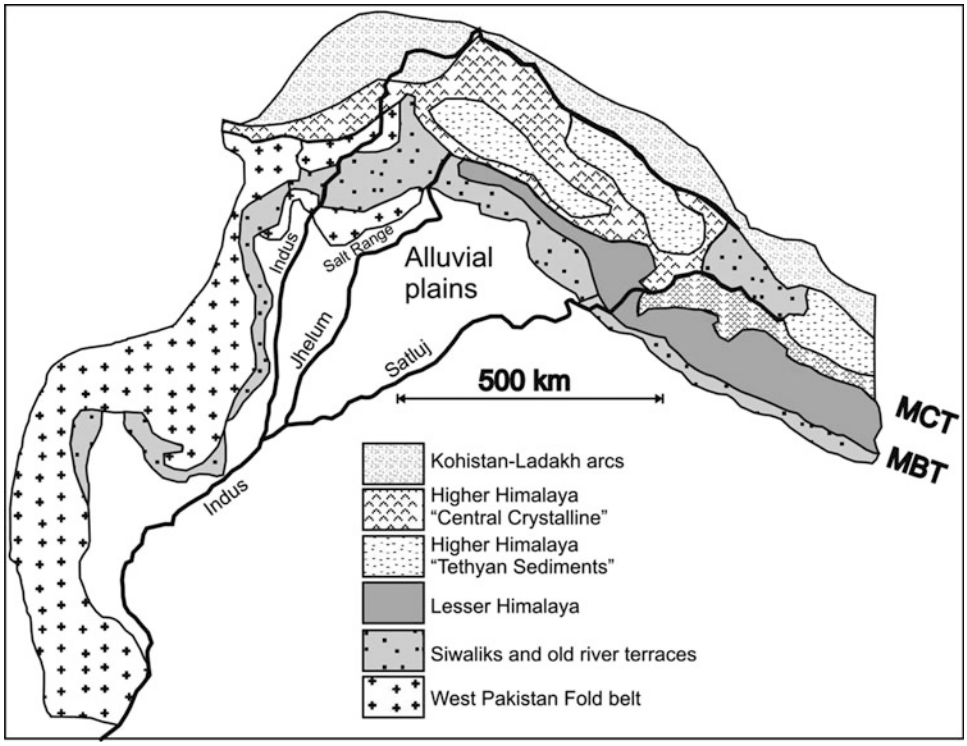

Fig. 2 Geology of the Indus Plains

syntaxial bends in the western and eastern extremities in western Pakistan and in Arunachal Pradesh (Gansser 1964). Drainage development in the western part led to the formation of the NE-SW trending Indus Basin, and the ENE-WSW trending Brahmaputra Valley in the eastern part—both basins being structural depressions whose evolution was largely governed by the western and eastern Himalayan syntaxis, respectively. In the central part, the Ganga Basin was formed as a WNW-ESE oriented elongated depression that is bounded by the outer Himalayan thrust sheets in the north and over significant areas to the south by the Bundelkhand Craton and its constituents.

The main geologic units that occur in the region of the Indus alluvial plains include the Himalayan thrust sheets, the Indus Suture Zone and the Kohistan Arc (Fig. 2). In its lower segment, the Indus flows parallel to the NE-SW trending west Pakistan fold belt. In the Ganga Plains, the depth to the basement is variable from a few kilometers in the northern and central parts to a few tens of meters towards the southern margin of the basin where the Pre-Cambrian outcrops are observed in the Indian Shield. West of Allahabad, the Archean rocks comprise the Banded Gneissic Complex and the Bundelkhand Complex (Fig. 3). The Proterozoic rocks include the Vindhyan Supergroup of rocks south and east of the Great Boundary Fault (Fig. 3 in Chap. 1)—a major tectonic feature which separates the Meso- to Neo-proterozoic Vindhyan sedimentary rocks from the Late Archean (2500 Ma) Berach Granite and the low-grade metamorphic Palaeoproterozoic volcano-sedimentary rocks of the Hindoli Group. Deccan Traps cover considerable tracts in the headwaters of the Chambal, Betwa and Ken Rivers. In the north, the Ganga and Yamuna catchments include the meta-sedimentary rocks of the Lesser Himalaya, and large granitic intrusive bodies. Southwards in the foothills, the foreland fold-thrust belt includes both the Paleogene Dharamshala Group and the Neogene Siwalik Group (Fig. 3).

The major regional geological features of the relatively narrow Brahmaputra Basin include the NE-SW trending Himalayan thrust sheets, the NW-SE trending Mishimi Thrust Belt, as well as the NE-SW trending Naga-Haflong-Dibang Thrust Belt in the south (Fig. 4). Further downstream, the Mikir Hills are followed by the Meghalaya or Shillong Plateau. The Brahmaputra River follows the northern margin of the Meghalaya Plateau and then bends to take its southerly course along the western margin of the plateau. The Brahmaputra Basin is divided into six zones from source to mouth into: (1) high plateau of Tibet (2) the Eastern Syntaxis (3) Mishimi Hills (4) the Himalayan Mountains (5) the Indo-Burman and Naga Patkai Ranges and (6) the plains of Assam and Bangladesh (Singh 2007a).

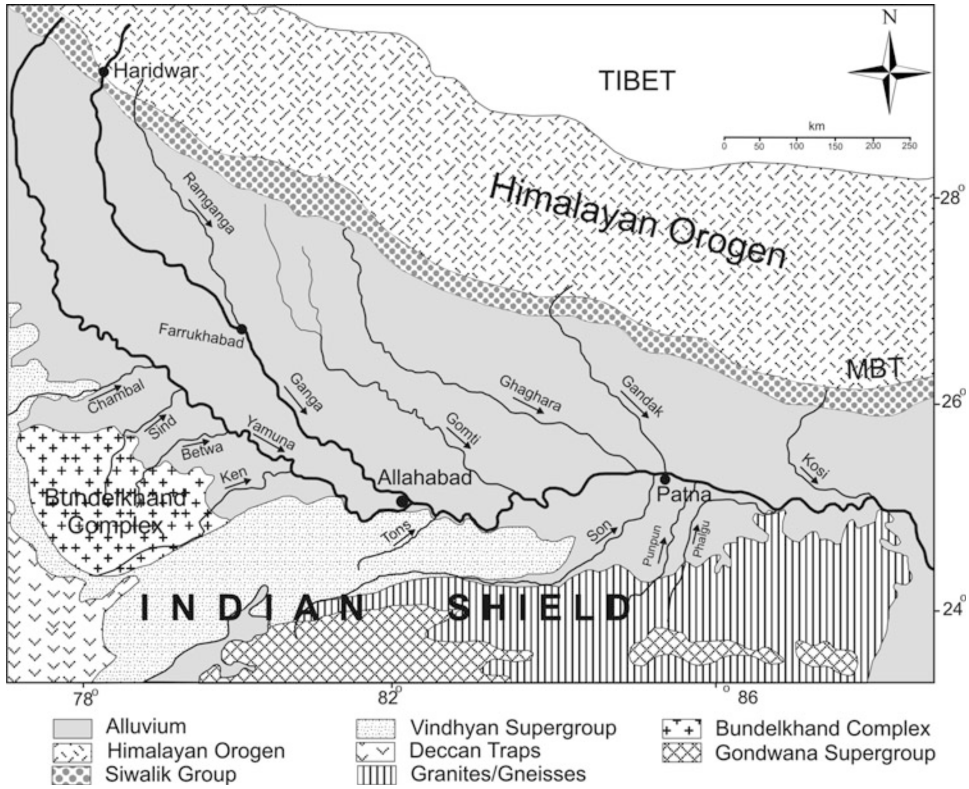

Fig. 3 Geology of the Ganga Plains

3 Basin Characteristics and Drainage

3.1 Indus

The Indus River (Fig. 5a), famous for supporting the Harappan Civilization (4.8–3.5 ka), is one of the largest rivers in the world in terms of its length, drainage area and average annual discharge (Table 1). Out of the total drainage area, ~506,753 km^2 of area lies in the semi-arid region of Pakistan and the rest in mountains and foothills. The Indus originates at an altitude of 5486 m a.s.l. from the Mount Kailas Range in the Tibetan Plateau on the northern side of Himalaya (Inam et al. 2007). The Indus falls into the Arabian Sea and forms an extensive alluvial plain and delta as well as the world's second largest submarine fan (Milliman and Meade 1983). The average annual suspended sediment load of 291 million tonnes/year ranks the Indus as one of the highest sediment load carrying rivers in the world. The Indus has a much lower water discharge compared to other rivers in this region, averaging ~3,000 m^3/s but can reach up to ~30,000 m^3/s during summer monsoons.

3.2 Ganga

The Ganga Plains have been built by sediments derived from two distinct hinterlands—the Himalaya in the north and the cratons to its south—which have had varying relative influence through geological time (Sinha et al. 2009). Mountain-fed tributaries of the Ganga such as the Yamuna, Ramganga, Ghaghra, Gandak and the Kosi are generally multi-channel, braided systems, characterized by discharge and sediment loads that are many times higher than those of the single-channel, sinuous foothills-fed and plains-fed river systems (Table 1). They also transfer a large quantity of sediments from their high relief catchments to the plains and consequently form large depositional areas (megafans). Some reaches of the Ganga e.g. between Allahabad and Varanasi show a meandering pattern possibly due to the presence of a shallow basement in the vicinity of the southern cratonic margin and decrease in sediment to water discharge ratio. Downstream of its confluence with the Chambal, the Yamuna also shows meandering pattern due to the relatively higher hydrological and sediment inputs from the cratonic hinterland. The foothills-fed (e.g. Baghmati, Rapti) and plains-fed (e.g. Burhi Gandak, Gomti) tributaries derive their sediments from the foothills and from within the plains, and a large proportion of this material is re-deposited in the plains after local reworking.

The largest of the cratonic tributaries of the Yamuna/Ganga (Table 1) is the Chambal which is ~1,000 km long and has a catchment area of 140,000 km^2, larger than any of the Himalayan tributaries of the Ganga. Flow volumes from the main six cratonic tributaries constitute ~20 % of total

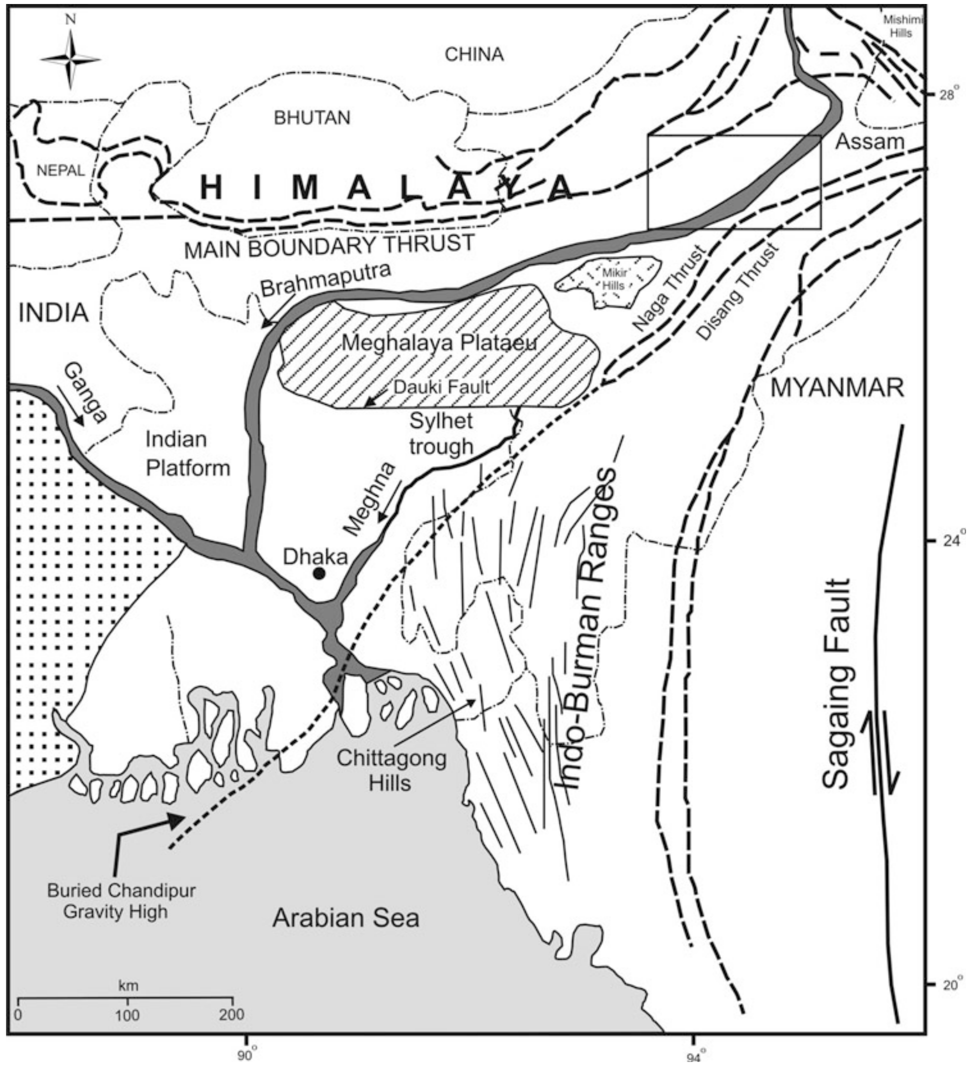

Fig. 4 Geology of the Brahmaputra Plains. *Box* shows the area covered in Fig. 7a

Ganga flow but can be very significant in certain reaches. The average annual sediment load of the Ganga at its mouth in Bangladesh is 599 million tonnes/year and together with the Brahmaputra it transports more than one billion tonnes of sediments into the Bay of Bengal every year.

3.3 Brahmaputra

The Brahmaputra Valley is the narrowest amongst the three river valleys being confined by the Himalayan thrust sheets to its northwest and the Naga-Patkai Hills and the Mikir Hills to the northeast as a result of convergence of multiple tectonic regimes. It can be subdivided into the North Brahmaputra Valley adjacent to the Himalayan foothills, and the South Brahmaputra Valley adjacent to the Naga foothills. The South Brahmaputra Valley extends southwestwards across the Dhansiri Valley after a break in the region of Barail Ranges into Cachar and Tripura Ranges.

The Brahmaputra, with a drainage area of 580,000 km^2 (50.5 % in China, 33.6 % in India, 8.1 % in Bangladesh and 7.8 % in Bhutan), is one of the world's largest rivers originating from the Chema-Yung-Dung Glacier in the Kailas Range of southern Tibet at an elevation of 5300 m a.s.l. (Goswami 1985). Two major tributaries of the Brahmaputra, the Dibang and the Lohit, join the upper course of the Brahmaputra, a little south of Pasighat and the combined drainage flows westward through Assam for about 640 km until near Dhubri where it abruptly turns south and enters Bangladesh. The Brahmaputra is then joined by several smaller tributaries both along the north as well as the south bank (Table 1).

The Brahmaputra ranks fifth among the world's largest rivers in terms of its annual mean discharge of 19,300 m^3/s measured at Bahadurabad, Bangladesh (Hovius 1998) and first in terms of its sediment yield (0.85–1.12 $t/yr/km^2$) (Table 1). Estimates of sediment load of the Brahmaputra at its mouth vary from 581 to 650 million tonnes/year and

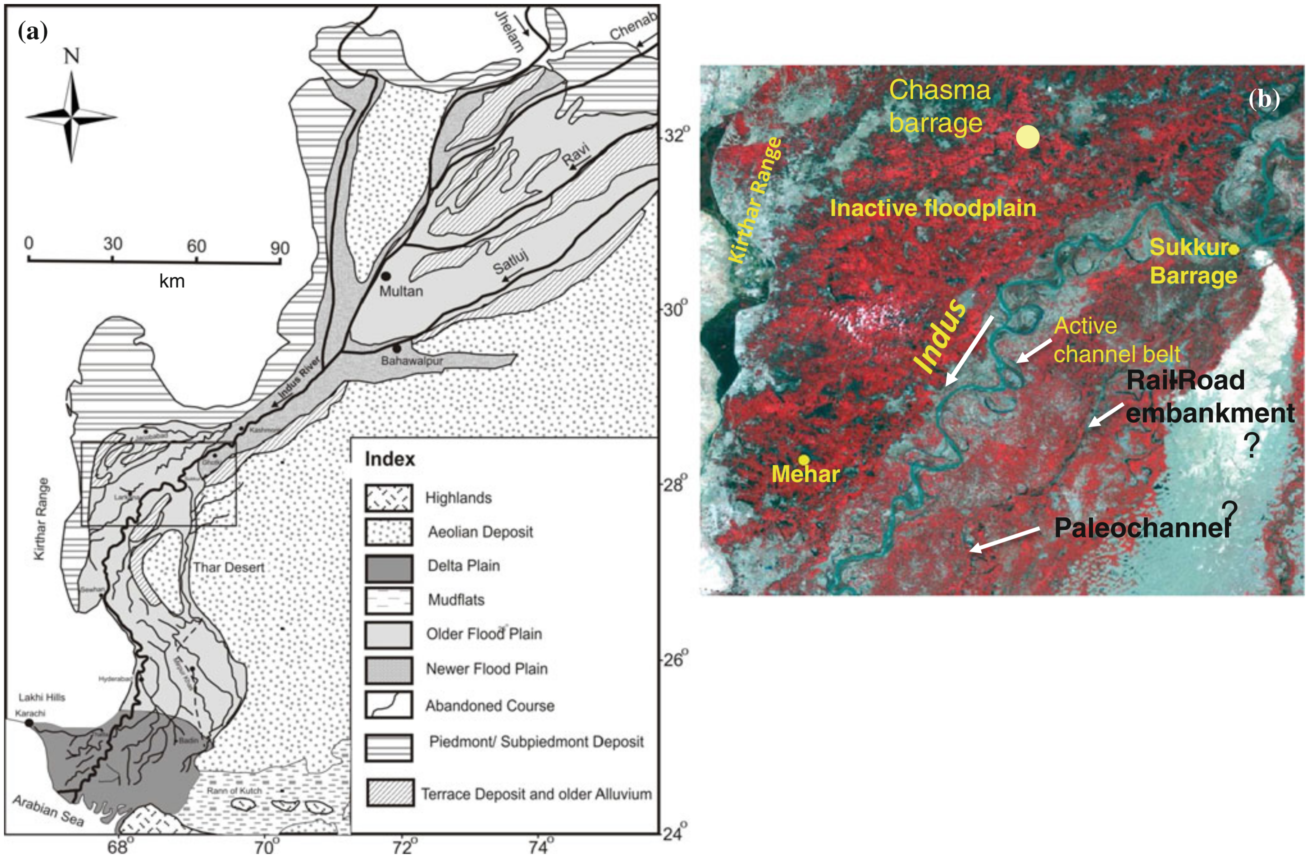

Fig. 5 **a** Geomorphological map of the Indus plains (Compiled after Giosan et al. 2006; Valdiya 2010). **b** Landsat image of a part of the Indus basin (marked as a *box* in **a**) showing major landforms

transport rates as high as 26 million tonnes are recorded during peak flows at Pandu (Goswami 1985). Amongst the largest rivers of the world located in monsoon-controlled regions, e.g. the Indus, Ganga, Brahmaputra, Irrawaddy, Mekong, Yangtze and Huanghe, the Ganga-Brahmaputra system presently contributes about 11 % of the total sediment flux to the world oceans (Goodbred and Kuehl 1999). About 30 % of the annual sediment load is accommodated within the floodplains and delta plains, ~40 % remains in the sub-aqueous delta and the remaining 30 % is transported to deep sea Bengal fans (Goodbred and Kuehl 1999).

4 Geomorphology and Landforms

The Indus has built a broad alluvial valley in the plains (~150 km wide on average) in the lower reaches and is bound by the Kirthar Hills to its west and Thar Desert to its east (Fig. 5a). Abandoned channels and frequent meanders of the Indus (Fig. 5b) have been mapped on both sides of the present course (Giosan et al. 2006; Gaurav et al. 2011) although most of these have now been obliterated due to large-scale agricultural activities. These palaeochannels are suggestive of a dynamic regime of the river in the past and most of these avulsions took place well upstream of the delta region between Kashmore and Sehwan (Jorgensen et al. 1993). A major westward avulsion of the Indus around Hyderabad (Pakistan) occurred in 1758–1759 that resulted in the establishment of the present-day course within the delta. The present course of the Indus is confined within the embankments and the modern floodplain widths are less than 5 km in most reaches.

The alluvial reaches of the Indus have undergone large-scale human interventions in terms of barrages and dams that have reduced the sediment discharge into the delta to only ~250 million tonnes instead of 300–675 million tonnes under natural conditions (Milliman et al. 1984). This has impacted the development of the Indus Delta significantly and has pushed the apex of the delta from its Holocene position between Hyderabad (Pakistan) and Sehwan to a much downstream position. The delta extends to the east into the Rann of Kachchh and forms an extensive mudflat that is often inundated during monsoons.

The rivers draining the Ganga Plains display significant geomorphic diversity in east-west as well as north-south transects (Fig. 6a) manifested as variability of fluvial

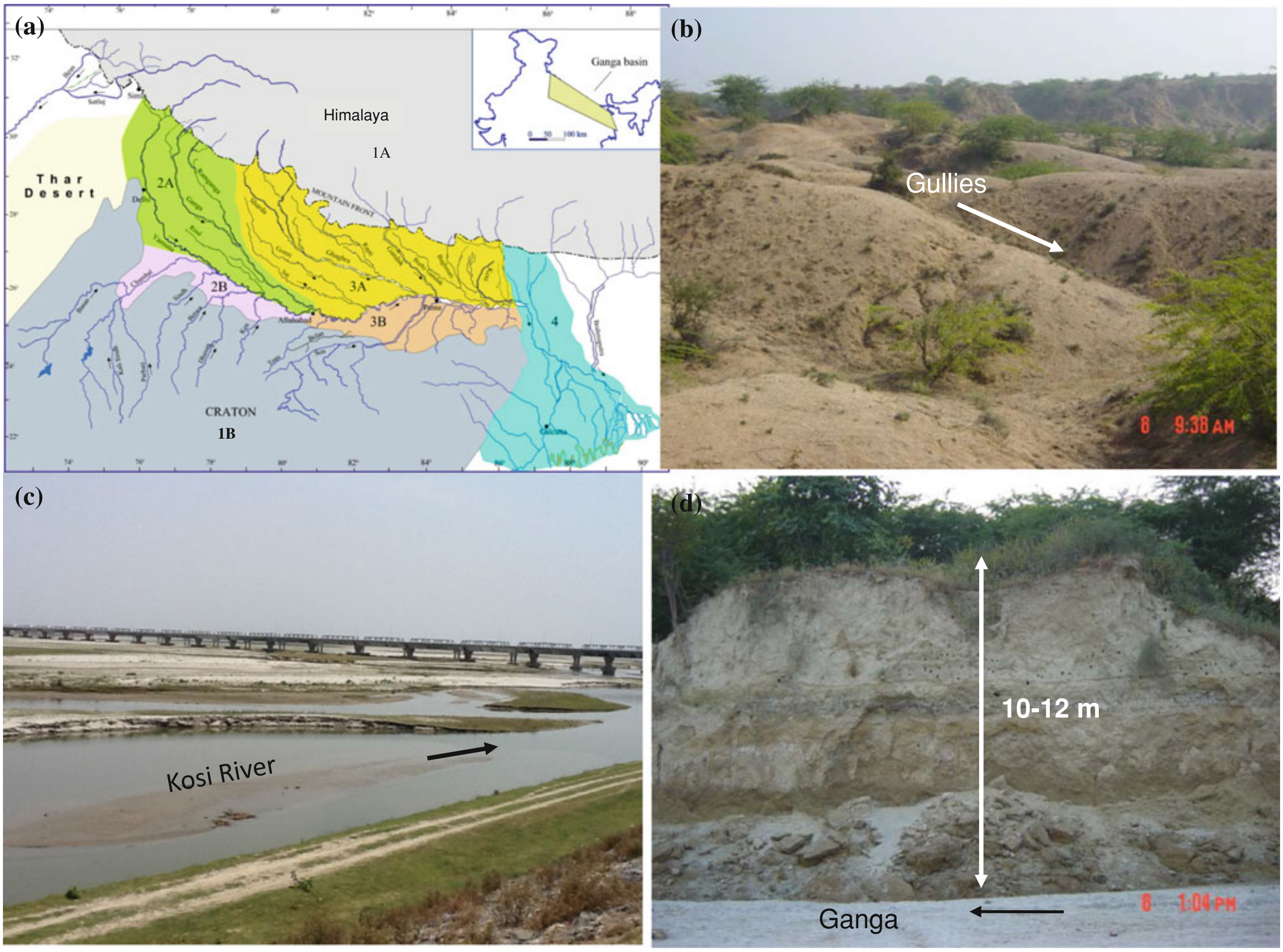

Fig. 6 **a** Genetic classification of the Ganga Plains (after Tandon et al. 2008) showing major geomorphic entities (*1A*, *1B*—Himalayan and cratonic hinterlands; *2A*, *2B* Western Ganga Plains divisible into Himalayan sources and cratonic sourced, *3A*, *3B*—Eastern Ganga Plains divisible into Himalayan-sourced and cratonic-sourced, *4*—Lower Ganga Plains and deltaic plains. **b** Dissected topography (badlands) in the Yamuna floodplain at Kalpi in WGP (*2B*). **c** Flat aggradational channel belt of the Kosi at Nirmali in EGP (*3A*). **d** Incised valley of the Ganga at Bithur (Kanpur) in the WGP (*2A*)

processes, spatial distribution of different geomorphic units and frequency of geomorphic elements (Sinha et al. 2005; Singh 2007b; Tandon et al. 2008). The northern and southern plains are influenced by two distinct catchments, the high elevation ranges of the Himalaya in the north and low-elevation cratons in the south respectively, the former resulting into piedmont plains and intermontane valleys and the latter in flat alluvial plains which are highly dissected (Fig. 6b). In the eastern Ganga Plains such as north Bihar, low stream power combined with higher sediment supply has resulted in less prominent valleys, frequent avulsion of rivers, and the inundation of large areas during monsoon floods. Many of these rivers such as the Kosi and the Gandak have formed large fans separated by interfan areas and flat aggradational channel belts (Fig. 6c). On the other hand, high stream power and lower sediment supply in the western Ganga Plains have resulted in incised valley systems (Fig. 6d) manifested as narrow valleys and wide interfluves. Such geomorphic diversity is in turn related to higher uplift rates and higher precipitation regimes in the hinterland of the eastern plains that not only result in higher sediment production but also in greater mobilization of sediments into the plains.

The Brahmaputra has a highly braided-anabranching channel in the plains of Assam and Bangladesh, marked by the presence of numerous mid-channel and lateral bars and islands, locally known as *chars* (Fig. 7a). Most of these bars are submerged during high flows and the river attains exceptional widths of the order of 18–20 km. The north-eastern region, especially the floodplains of the Brahmaputra, is dotted with a large number of wetlands or *beels*, which have tremendous ecological significance as unique habitats for an exquisite variety of flora and fauna. The *beels* function as floodwater retention basins and traditional fisheries. Over 3500 such wetlands have been identified in Assam, of which 177 are more than 100 ha in size. One of the most distinctive

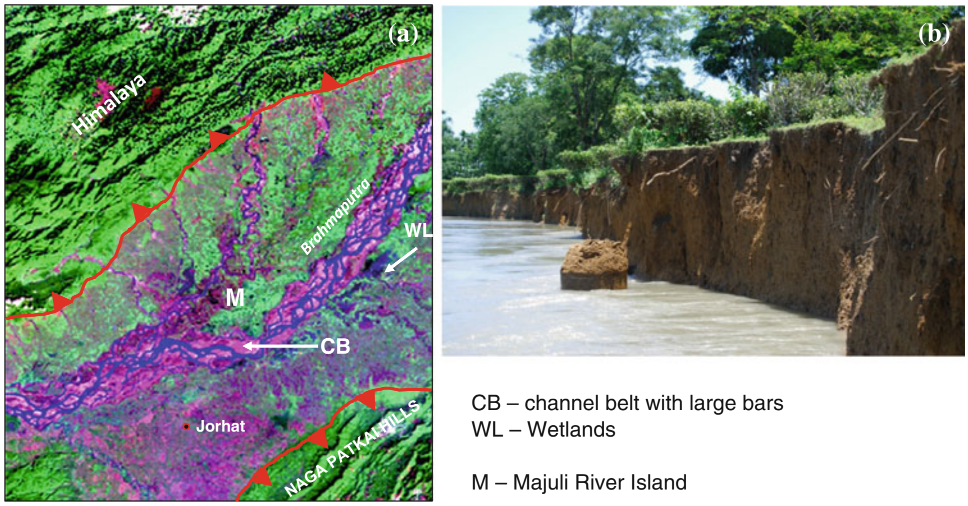

Fig. 7 **a** Landsat image of a reach of the Brahmaputra River (see *box* in Fig. 4) showing major geomorphic features. **b** Severe bank erosion along Brahmaputra River at Rohomaria, ~20 km NE of Dibrugarh

geomorphic elements of the Brahmaputra system are large riverine islands (Fig. 7a), some of which are more than 100 years old. Locally called '*Majuli*' (meaning land locked large island), these islands differ from the usual sand bars in terms of their size and evolutionary history. Most reaches of the Brahmaputra are prone to large-scale channel dynamics and bank erosion (Fig. 7b).

The Ganga-Brahmaputra (G-B) Delta (Fig. 8) is considered as the largest active delta in the world formed by frequent avulsion of both Ganga and Brahmaputra over a time scale of hundreds of years. The channel courses of the Ganga and the Brahmaputra Rivers were separate until about 200 years ago; the Brahmaputra first occupied its present position as late as 1830 and has switched between the present course and an eastern course (Meghna River) more than once in the historical time period (Goswami 1985). Systematic geomorphic mapping of the G-B Delta has distinguished three major units (a) lower floodplain and delta margin (b) upper delta plain and (c) lower delta plain. These geomorphic units show significant differences in terms of sedimentary facies and stratigraphic development (Goodbred and Kuehl 2000). One of the interesting features is the development of thick estuarine deposits and the persistence of intertidal facies in the deltaic successions which indicates that sediment supply to the delta system has been sufficient to infill accommodation created by the rapid sea-level rise (Sinha and Sarkar 2009).

5 Basin Fills and Alluvial History

Geophysical surveys together with drilling have revealed that the IGB basement is uneven and cut up by faults (Sastri et al. 1971). This has resulted in the formation of individual depressions separated by ridge like features or 'highs'. Some of these depressions like the Sarda and the Gandak are deeper in the proximal zone i.e. towards the Himalayan Mountain Front and have accumulated sediments up to 6–7 km thick. Deep drilling in the Ganga Basin by the Oil and Natural Gas Corporation (ONGC) of India, allowed the recognition of Siwalik rocks at many locations below the Ganga Plains sediments. Despite the large thickness of alluvial sediments on these plains, little is known about the sub-surface Quaternary sediments of the plains. The stratigraphic units include the Older Alluvium (Banda, Varanasi, and Bhangar) and the Newer Alluvium (Bhur and Khadar) of earlier classifications (Table 2). The Bengal Plains constitute the eastern extreme of the Ganga Plains. In its eastern side, the Lalmati Terrace is ~30 m a.s.l. The Barind Tract lies in the north and has three topographic levels. The Madhupur Terrace is made up of reddish brown sediments with abundant ferruginous/calcareous concretions that are similar to the Bhangar of the Ganga Plains.

In the last few years, the shallow subsurface in the southern part of the Ganga Plains (Ganga-Yamuna-Betwa) has been studied using a combination of resistivity surveys and shallow sediment coring (Sinha et al. 2007, 2009). Based on these studies, it has been established that: (1) the Ganga has been near to its present location since at least 30 ka (2) the Ganga Valley and the interfluve to the south between the Ganga and Yamuna have existed in their spatial domains for at least tens of thousands of years (3) thick wedges of red feldspathic sand and gravel underlie much of the southern foreland basin at shallow depth where the uppermost red feldspathic strata in the Kalpi (on Yamuna) section have yielded an age of ~119 ka (Gibling et al. 2005) (4) widespread fluvial activity took place in Marine Isotope Stages (MIS) 5 and 3 in several parts of the basin (Singh 2007b; Srivastava et al. 2003), and (5) the fluvial aggradational events are bounded by discontinuities marked

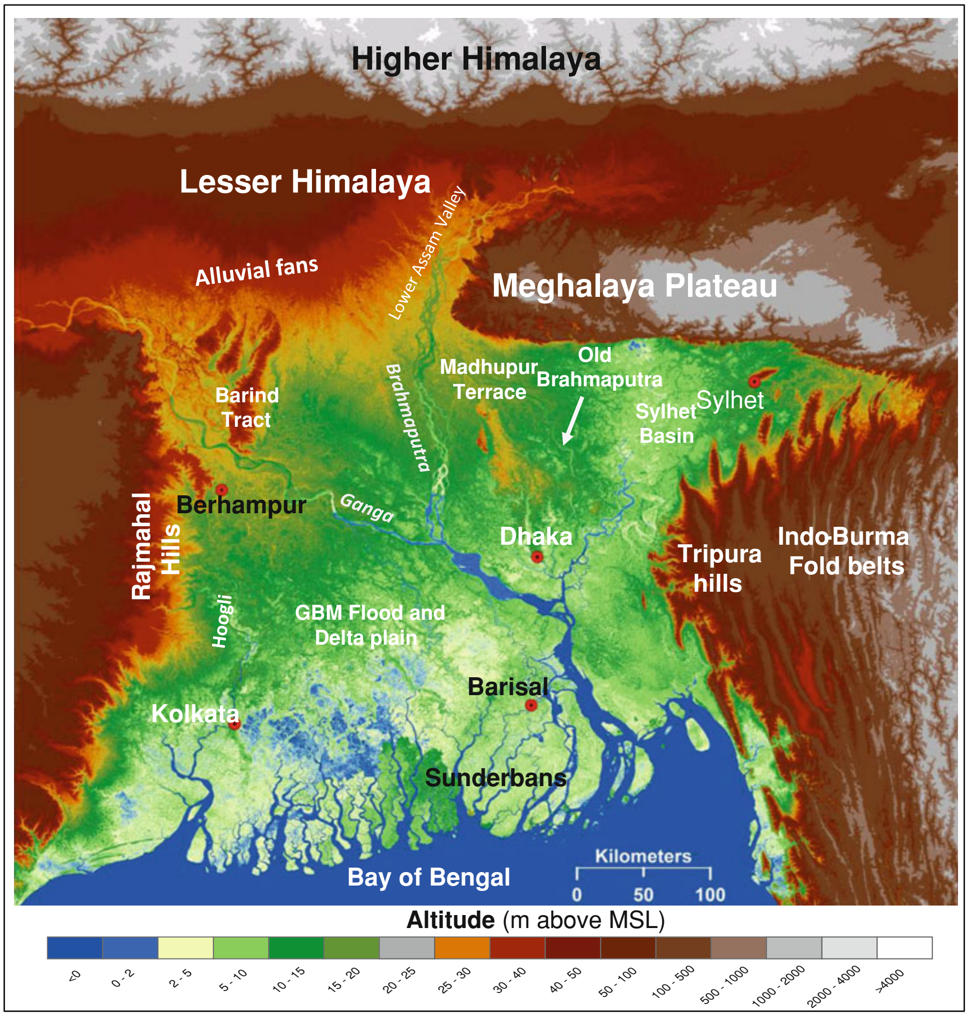

Fig. 8 Digital elevation map of the lower Brahmaputra and Ganga Basins showing major landforms

Table 2 Comparative morphological characteristics of the three major drainage systems

Basinal setting	Indus	Ganga		Brahmaputra
		Western Ganga Plain	Eastern Ganga Plain	
Proximal	Piedmont sub-piedmont	Piedmont (Bhabhar[a])	Piedmont (Bhabhar[a])	Piedmonts bordering various thrust sheets (Himalayan, Mishimi, Naga-Haflong)
Medial	Meandering-Braided	Sandy-Braided, locally sinuous reaches	Sandy-Meandering-Braided	Sandy-Braided-anabranching channels
				Southern tributaries highly sinuous
	Alluvial plain	Valley-interfluve (*Bhangar-Khadar-Bhur*[b–d]) Incised channels; Badland development in interfluves of cratonic rivers	Dominant fan-Interfan setting Megafans, Avulsive channels common e.g. Kosi, Baghmati	Wide channel belts (∼20 km), wetlands (*beels*), and large bars and alluvial islands (*majulis*), no large alluvial fans possibly due to limited space
Distal	Deltaic plain		G-B deltaic plain	G-B deltaic plain, relict terraces (Barind tract, Madhupur surface, Lalmai surface)

[a] *Bhabhar*: Small fans and cones of gravelly deposits that form an apron along the frontal margin of the foothills and the zone of the mountain front
[b] *Khadar* (Newer Alluvium): Grey micaceous fine to medium-grained sand with clay intercalations and terraced alluvium—grey to light brown, quartz feldspathic fine grained sands
[c] *Bhur sands*: 3–10 m thick fine-grained aeolian sand accumulations
[d] *Bhangar* (Older Alluvium): G-B Ganga Brahmaputra

by degradational relief surfaces, palaeosols, groundwater cementation, and the local development of lakes, ponds and aeolian (*bhur*) deposits (Gibling et al. 2005).

6 Major Concerns and Issues

All three basins, the Indus, Ganga and Brahmaputra, are known for rapid migration and avulsion of their channels as manifested by several palaeochannels and abandoned meanders on older floodplain surfaces. The sediment-laden water of the Indus has created many water resource management problems, mainly in the upper Indus basin, and the construction of embankments on both sides of the river, dams and barrages have worsened the situation. The Indus flood of 2010 was triggered by unusual rainfall but the influence of engineering structures such as barrages and embankments compounded the problem due to accelerated aggradation of the river bed and reduced the carrying capacity of the channel (Gaurav et al. 2011). The eastern parts of the Ganga Plains are well-known for the dynamic rivers draining the region. Apart from the Ganga, several tributaries such as the Kosi, Gandak and Baghmati draining the north Bihar Plains have created havoc in the region due to their hyperavulsive nature and extensive flooding (Gole and Chitale 1966; Jain and Sinha 2004). The Brahmaputra is notorious for severe bank erosion due to rapid movement of its thalweg and once again excessive sediment load of the river is considered to be the main cause for such a dynamic regime (Goswami 1985).

Continuous interventions and excessive extraction of water for human use have impacted all three river basins. Large tracts of the Ganga Basin suffer from water quality problems due to industrial and municipal effluents being discharged into the river. At the same time, the upper reaches of the Ganga River have undergone loss in biodiversity due to dams and barrages. Deforestation and land cover changes are common problems in all three basins and recent results in the upper Ganga Basin (Yu et al. 2007) indicate that a large part of forest and barren land has been converted to agriculture areas during the last two decades.

7 Summary and Conclusions

The Indus-Ganga-Brahmaputra Plains are a part of the Himalayan foreland basin that is drained by three mountain-fed large river systems of the world. The plains are marked by high geomorphic diversity as they are influenced variably by different geologic, tectonic and climatic regimes over wide tracts that extend along the length of the Himalayan Arc and the Himalayan syntaxial bends. The Indus is characterized by a narrow alluvial plain and a dynamic regime; the Ganga Plains in the western part are marked by the presence of valley-interfluves formed over several tens of thousands of years and by megafans in the eastern part; the Brahmaputra system being the wettest part of the plains is marked by very wide channel belt with the development of large bars, exceptionally large alluvial islands, and large number of wetlands. Several parts of the plains are impacted severely by avulsive shifts of the drainages as well as flooding. Extended use of the plains over thousands of years by large populations has impacted the plains through many forms of anthropogenic disturbances including large-scale land use/land cover changes, pollution linked to agricultural practices, urbanization and river engineering.

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