
The Kosi Megafan: The Best-known Himalayan Megafan

Rajiv Sinha

Abstract

The conical-shaped Kosi Megafan in north Bihar Plains (eastern Ganga Plains), eastern India is one of the most cited megafans in the world in the international literature. Named after its principal drainage, the Kosi River, this megafan has a distinct convex-up topography. Numerous palaeochannels on the fan surface represent the remnants of the earlier courses of the Kosi River through its westward journey during the last 200 years. Like other fans in the world, the Kosi megafan has formed due to high sediment flux, fluctuating discharge regime and the availability of large accommodation space. It is believed that the fan building process of the Kosi continues till date and this explains the unstable behavior of the river. The construction of a barrage close to the mountain exit and embankments on both sides of the river have certainly retarded the natural fan-building processes but the Kosi Megafan is still one of the most fascinating landforms on this planet.

Keywords

Kosi river • Megafan • Inland delta • Alluvial cone • Avulsion • Palaeochannels • River dynamics

1 Introduction

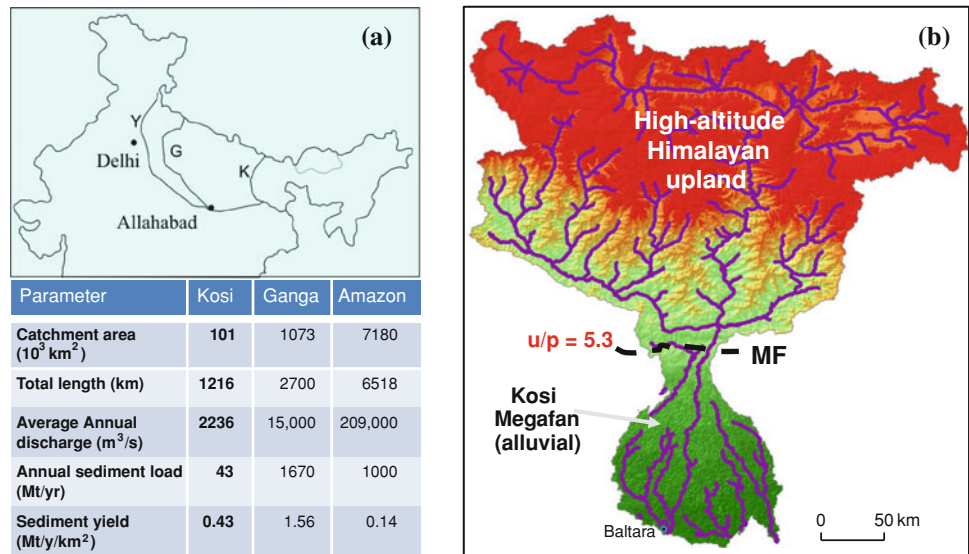
A megafan is a large (10^3 – 10^5 km²), fan-shaped (in plan view) mass of clastic sediment deposited by a laterally mobile river system that emanates from the outer point of a large mountainous drainage network. Megafans form in alluvial plains and are characterized by a distinct morphology, specific tectono-climatic setting, unique hydrologic regime and complex sedimentary processes involved in their formation and preservation. As a result, megafans are quite localized (15°–35° N and S) in terms of their occurrence (Leier et al. 2005). Two most important characteristics of the

megafans are (a) the principal drainage feeding the fan system which is generally quite dynamic and sweeps through the entire fan surface over a period of time, and (b) a typical distributary drainage network radiating from a mountain exit. The implicit controls for the formation of megafans would therefore include a source of abundant sediment supply such as an active orogen and a large accommodation space such as flat alluvial plain to allow for extensive sediment deposition as well as frequent migration of channels.

Geomorphic complexity of megafans has drawn enormous attention of researchers from all over the world but the Kosi megafan has remained an attractive example in most studies due to its large size, active Himalayan hinterland and exceptionally high sediment flux. The avulsive shifts of the Kosi River, dominantly westward (Fig. 2b), have been dramatic and the available records suggest a migration of over 150 km in 200 years (Gole and Chitale 1966; Wells and Dorr 1987). A recent eastward avulsion

R. Sinha (✉)
Department of Earth Sciences, Indian Institute of Technology,
Kanpur 208016, India
e-mail: rsinha@iitk.ac.in

Fig. 1 Location map and characteristics of the Kosi Megafan. With a large upland to plains area ratio and a high sediment flux, the Kosi Megafan system has evolved a rapidly aggrading landform in the Himalayan Foreland. Mountain Front (MF) marks the sharp topographic break and separates the high altitude mountainous upland and the flat alluvial plains. G Ganga, Y Yamuna, K Kosi, u/p upland area to plains area ratio



(a sudden shift of channel to another location) in August 2008 resulted in a shift of ~ 120 km (Sinha 2009). This is the largest avulsive shift in a single event recorded so far anywhere in the world and this resulted in unprecedented floods in Nepal and north Bihar.

2 Location and Environment

The Kosi Megafan has a maximum length of 150 km from apex to the confluence to the Ganga and a maximum width of 120 km in its mid-fan region. With the total area of $\sim 10,328$ km² (fan area), the Kosi Megafan mostly lies in north Bihar Plains (eastern Ganga Plains) except for its apical part, which falls in Nepal. The principal drainage of the megafan, the Kosi, originates at an elevation of $>5,500$ m a.s.l. in Tibet and has a very large, tectonically active hinterland mostly lying in Tibet and Nepal Himalaya (Fig. 1b). The area of the mountainous/upland part of the Kosi drainage basin is more than 5 times larger than the part located in the plains (u/p ratio 5.3, Sinha and Friend 1994).

The Kosi River enters the plains at Chatra in Nepal and then flows for ~ 80 km in Nepal including the barrage at Bhimnagar before entering the north Bihar Plains in India. The river flows for ~ 160 km in north Bihar before meeting the Ganga River near Kursela and builds a large fan-shaped landform (Fig. 2a). The main channel of the Kosi in the alluvial reach is braided throughout and the thalweg keeps oscillating between the two ends of the 5–7 km wide channel belt as the river moves from upstream to downstream.

The Kosi is a typical monsoonal river and the monthly discharge of the river generally starts to peak in the month of June with the maximum in August/September. The average annual discharge (Q_{av}) of the Kosi is $\sim 2,236$ m³/s. The

average monsoon discharge computed for a period of 1985–2002 is 5,156 m³/s that is ~ 5 times higher than the non-monsoon discharge of 1,175 m³/s (Sinha et al. 2008). Such large difference between monsoonal and non-monsoonal discharge makes the river vulnerable to flooding as the shallow river sections cannot accommodate the excess discharge.

In terms of sediment flux, the average annual suspended sediment load for the Kosi at its most downstream station (Baltara) is 43 Mt/year (Sinha and Friend 1994) even though a large part of total sediment flux from the hinterland is intercepted at the barrage. For a total catchment area of $\sim 101,000$ km², modern annual sediment yield of the Kosi is 0.43 Mt/km²/yr. Frequent avulsive movement of the Kosi River (Fig. 2b) has been attributed as *autocyclic* (resulting from processes within the system) and *stochastic* (non-deterministic behavior), which is typical of most alluvial fans across the world. However, the average avulsion frequency of 24 years (i.e. avulsion once in 24 years) for the Kosi is among the highest frequencies in the world compared to 1,400 years for the Mississippi River. High sediment flux and rapid aggradation within the embankments have been considered as the primary reasons for avulsion and flooding in this region (Sinha 2009; Chakraborty et al. 2010).

The Kosi River was embanked on both sides in 1955–1956 (Fig. 2a) and the Kosi Barrage became operational in 1963 as a part of flood protection measure and to provide irrigation for increasing agricultural productivity. However, the embankments have breached frequently and the August 2008 event was the 9th breach in the last ~ 50 years. Most of these breaches have resulted in large floods. Further development of irrigation and rail-road network in the megafan region has resulted in several

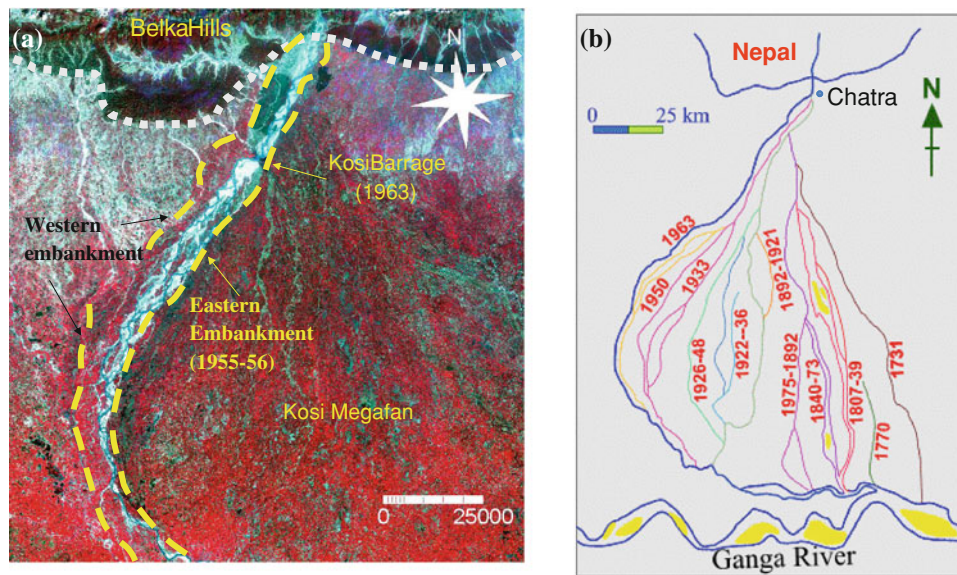


Fig. 2 **a** The Kosi Megafan has a typical conical shape and the fan surface is characterized by numerous palaeochannels as seen clearly on the satellite image. **b** Using historical maps, location of several palaeochannels corresponding to different time periods are shown (after Gole and Chitale 1966). The Kosi River was embanked by

1955–1956 and the barrage was operational by 1963. The river was thus confined and the natural fan building process was retarded. However, a large shift occurred in August 2008 and the river briefly occupied the central position of the fan. The river was put back within the embankments in January 2009 through engineering interventions

adverse effects viz. drainage congestion and waterlogging, rise of river bed level, and reduction in crop productivity due to reduced silt flux on the floodplains.

3 Landforms and Landform Diversity

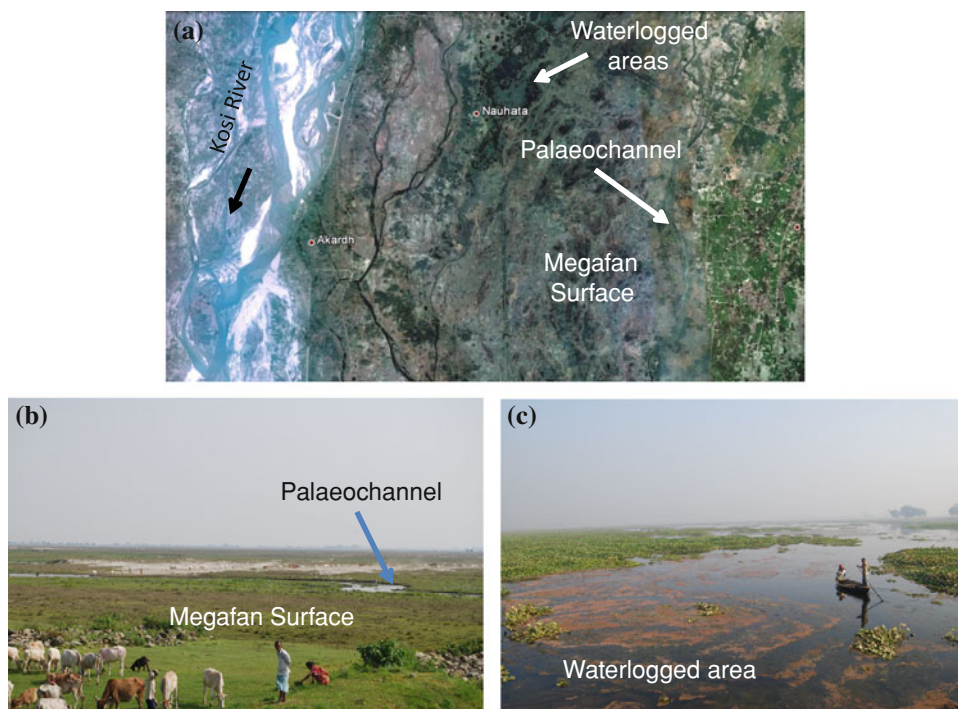
The first systematic description of geomorphology of the Kosi Megafan was provided by Geddes (1960). Based on closely spaced contours, Geddes demonstrated that the Kosi Megafan (termed as ‘cone’) has a convex topography across the fan with a typical radial pattern of distributaries. Geddes recognized that the major factors controlling the size of the cone (megafan) are discharge and silt load and documented that “even in a normal season, the Kosi’s sands may raise the belt of floodplain by a foot”.

The Kosi Megafan has also been described as ‘inland delta’ (Gole and Chitale 1966) built by large sediment flux from the Himalayan orogen. Using topographic contours, the authors suggested that the Kosi has built a conical delta with contours running almost circumferentially with the center situated in the vicinity of Belka Hill, west of Chatra (Fig. 2b). The dynamic behavior of the Kosi River was attributed to delta cone building process. Since the radial distance from the apex to the toe of the base plane of the delta is maximum in the central part, the cone building, and hence, the shifting of the river is expected to be slower compared to the eastern and western edges of the cone. This was

suggested to be the main reason why the north-south course of the Kosi River during 1807–1879 was more stable. The rate of movement of the Kosi River and cone building are therefore attributed to rate of sediment accumulation on the cone and the deficient river slope. The authors considered that the cone building activity of the Kosi is still incomplete and this explains the unstable behavior of the Kosi River compared to the adjoining Gandak River which has also built a megafan. Although the authors contested the earlier idea of a sudden eastward shift (Wells and Dorr 1987), the August 2008 avulsion (Sinha 2009) proved this to be true.

The term “inland delta” is no longer used to describe large fans. The term ‘megafan’ was first used by Gohain and Parkash (1990) who also provided a detailed geomorphic description of the landforms on the Kosi Megafan surface. They distinguished four distinct geomorphic surfaces (L1–L4) on the Kosi Megafan, well separated by elevation differences. The active channel course with low bars forms the lowest surface (L1) and the remaining three surfaces are parts of the active floodplain. The lowest, nearly barren floodplain surface (L2) is 0.5–0.9 m higher than the water surface during the low flow period and is flooded every year. The next sparsely vegetated surface (L3) is ~1 m higher than the lowest floodplain and is submerged during high flows of annual floods. The highest floodplain surface (L4) is 0.5–0.8 m higher than L3 and comprises the islands and banks covered by grasses, tall trees which get flooded during the peak discharge.

Fig. 3 **a** Characteristics of the megafan surface as seen on the Google Earth image and during field visits. **b** The flat megafan surface has minor undulations due to several palaeochannels as seen on ground. **c** Large waterlogged patches are conspicuous on the satellite images and are generally covered by algae and water hyacinths for most parts of the year



The fan surface as seen on satellite image (Fig. 3a) is characterized by numerous ‘*dhars*’ (small channels) representing palaeochannels of the Kosi River which are partially activated during the monsoon season (Fig. 3b). Large waterlogged patches, locally called “*chaur*s”, on the megafan surfaces (Fig. 3a, c) are conspicuous and most of them are low-lying depressions which are fed by rainwater and groundwater seepage. Some of these waterlogged patches in the lower reaches and close to the embankments are very large which are related to seepage along the embankment but may partly represent accumulation of floodwater after overbank flooding.

The transverse profile of the megafan is broadly convex-up but highly irregular due to numerous palaeochannels dissecting the megafan surface; the eastern part of megafan is lower than the western part (Chakraborty et al. 2010). The longitudinal profile of the megafan is concave-up with a general slope from north to south, being steeper in the north (55–75 cm/km) and flatter in the south (6 cm/km). Like many other megafans across the world, the presence of radiating channels on the fan surface reflects a divergent slope attributed to convex-up lateral geometry. Based on the palaeochannel network and their discordant relationship, Chakraborty et al. (2010) identified three accretionary lobes on the Kosi Megafan although their relative chronology is not clear. An important conclusion of this work was the negation of the idea of continuous westward movement of the river during the pre-embankment period. The authors instead suggested, based on the analysis of historic maps, a random and oscillating shifting of the river except for a

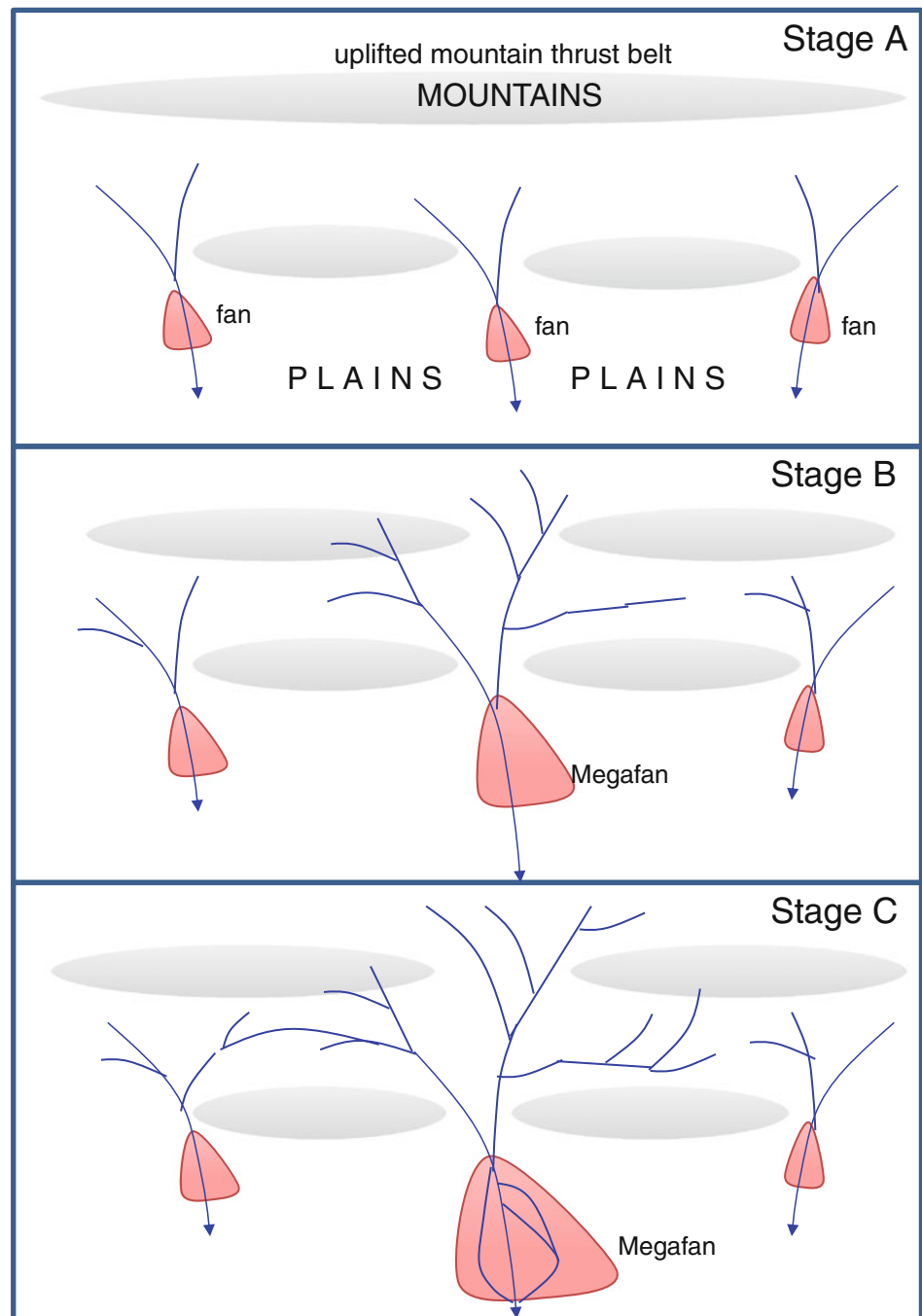
prolonged position in the axial part of the river as documented earlier by Gole and Chitale (1966).

4 Evolutionary History

Limited literature on the geologic and geomorphic evolution of megafans suggests three important conditions to form such large-scale landforms: (a) abundant sediment flux (b) adequate relief and (c) large accommodation space. Although several Himalayan rivers form a point-source dispersal system, only a few of them such as the Kosi has formed a megafan apparently due to enormous sediment flux from a large upland area and a flat alluvial terrain which provided accommodation space for a positive topography to build up over time. Leier et al. (2005), in a compilation of 33 megafans across the globe, also suggested that rivers with moderate to large drainage basins with moderate to high relief and large but fluctuating discharge are more likely to form megafans.

Megafans usually form at the mountain-plain interface in tectonically active areas. A simple geometric model was proposed by Horton and DeCelles (2001) for the evolution of megafan (Fig. 4). Initial stage (A) involves the uplift of the mountain thrust belt and several alluvial fans are deposited along the topographic divide associated with the small stream having small catchment area. The second stage (B) starts when the small stream with low stream power cannot cross the downslope structure. Consequently, the catchment area increases due to headward erosion and river piracy and

Fig. 4 A schematic diagram showing stages in the evolution of megafan. *Stage A* involves the uplift of the mountain thrust belt and deposition of several alluvial fans along the topographic divide associated with the small stream having small catchment area. In *Stage B* one of the small streams increases the catchment area by headward erosion and river piracy and megafan starts to form in the mountain thrust belt. The final stage (*Stage C*) involves further increment of catchment area and integration of drainage network in the mountain thrust belt resulting in large-scale megafan deposition



megafan starts to form in the mountain thrust belt. The final stage (C) involves further increment of catchment area and integration of drainage network in the mountain thrust belt resulting in large-scale megafan deposition. Our knowledge on the evolution of the Kosi Fan is severely handicapped because of the lack of sub-surface stratigraphic data which hold the clues for long-term geomorphic development of such unique landforms. However, all the available records suggest that the Kosi Fan formed during late Quaternary period but

more precise estimates would have to wait for absolute dates of fan deposits.

5 Conclusions

The Kosi megafan is one of the most cited megafans in the world. Large size, dynamic river regime and very high sediment flux are some of the most significant characteristics of

the Kosi Megafan system. Tectonically active Himalayan hinterland and highly variable discharge regime have resulted in a very efficient sediment dispersal system and the flat alluvial plains have facilitated the formation of a fascinating landform in the Himalayan Foreland. Described as 'inland delta' and 'alluvial cones' by earlier workers, the 'megafan' term is fairly well accepted now for these large-scale landforms with distinctive morphology and hydrological regime. The natural processes of fan building have been somewhat retarded due to large-scale interventions on the Kosi River in the form of barrage and embankments. Long-term evolutionary history of the Kosi fan remains unexplored.

References

- Chakraborty T, Kar R, Ghosh P, Basu S (2010) Kosi megafan: historical records, geomorphology and the recent avulsion of the Kosi River. *Quatern Int* 227:143–160
- Geddes A (1960) The alluvial morphology of the Indo-Gangetic plain: its mapping and geographical significance. *Inst British Geogr Trans Pap* 28:253–276
- Gohain K, Parkash B (1990) Morphology of the Kosi megafan. In: Rachoki A, Church M (eds) *Alluvial fans: a field approach*. Wiley, Chichester, pp 151–178
- Gole VC, Chitale VS (1966) Inland delta building activity of Kosi River. *J Hydraul Div ASCE* 92:111–126
- Horton BK, DeCelles PG (2001) Modern and ancient fluvial megafans in the foreland basin system of the central Andes, southern Bolivia: Implications for drainage network evolution in fold-thrust belts. *Basin Res* 13:43–61
- Leier AL, DeCelles PG, Pelletier JD (2005) Mountains, monsoons and megafans. *Geology* 33:289–292
- Sinha R (2009) The great avulsion of Kosi on 18 August 2008. *Curr Sci* 97:429–433
- Sinha R, Bapalu GV, Singh LK, Rath B (2008) Flood risk analysis in the Kosi river basin, north Bihar using multi-parametric approach of analytical hierarchy process (AHP). *Indian J Remote Sens* 36:293–307
- Sinha R, Friend PF (1994) River systems and their sediment flux, Indo-Gangetic plains, northern Bihar, India. *Sedimentology* 41:825–845
- Wells NA, Dorr JA (1987) Shifting of the Kosi River, Northern India. *Geology* 15:204–207