Sediments and Soils in the Floodplain of Bangladesh: Looking up to the Himalayas?

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1. INTRODUCTION

The 120 million people living in Bangladesh occupy one of the world's largest delta complex which is affected every year by floods, riverbank erosion and sediment accumulation. Are these floods and sedimentation processes influenced by land use changes, deforestation and human misbehaviour in the middle mountains of the Himalayas, as it is widely suggested by Upreti (1993)?

Water, erosion and accumulation of sediments from the Ganges, Brahmaputra and Meghna rivers largely dominate life in Bangladesh. Twenty percent of the country or 2/3 of the arable land are under water every year during a normal monsoon season (ISPAN, 1993). The flood of the century submerged 58% of Bangladesh in 1988, and 2000 people died. One million people are affected by riverbank erosion every year (Rana, 1993). The annual average discharge of all rivers into the Bay of Bengal is 35,000 $m^3 s^{-1}$ of water (ISPAN, 1993), and 2 billion t yr^{-1} of sediments are deposited in the delta each year (Rana 1993, ISPAN, 1993).

The disastrous effect of floods and river sedimentation in Bangladesh is often attributed to a direct highland-lowland interaction. The human intervention in the Himalayas was often blamed as playing the major role. However, this view contrasts with the scale-concept of Ives and Messerli (1989, Figure 1). They argued that, at the micro-scale, human impact can be dominant, but at the macro-scale of highland-lowland interactions (Himalaya-Floodplain interactions), the natural impact becomes the dominant force and the human fingerprint becomes insignificant.

In this article, we illustrate the Himalaya-Bangladesh interactions by using the example of sediments and sediment transport. Can we find the Himalayan land use degradation signal in the floodplain of Bangladesh? What controls sedimentation in the floodplain, and where is the material coming from? First we look at the relationship between the Quaternary history, sedimentation and soils in Bangladesh, which represents the large-scale and long-term component (10^2 to 10^4 years). Then we will give two examples on the effects of sedimentation on soil fertility and the dynamics of erosion and accumulation processes. This represents the short-term view (1-10 years) at the local-regional scale. Finally, we try to put the findings into the context of the highland-lowland interactions to contrast the impact of natural versus anthropogenic processes. We hope to contribute to the view that processes need to be examined at different scales in time and space, and all complexities need to be included if we hope to gain a better understanding of the 'real' highland-lowland interaction processes.

We fully confess that the views presented are incomplete, and many processes are not well understood. We see this contribution as an attempt to stimulate more discussion on a very complex problem which has wide ranging implications and to which the research community has given insufficient attention.

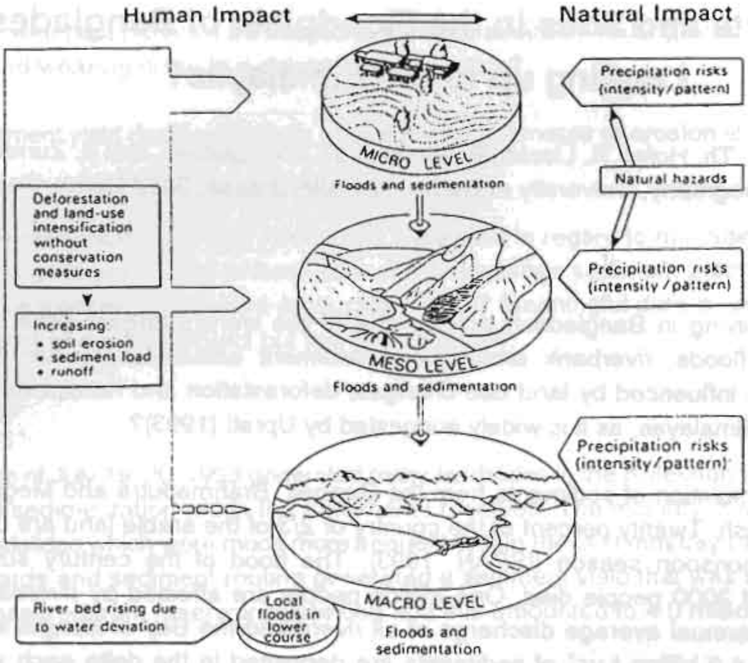


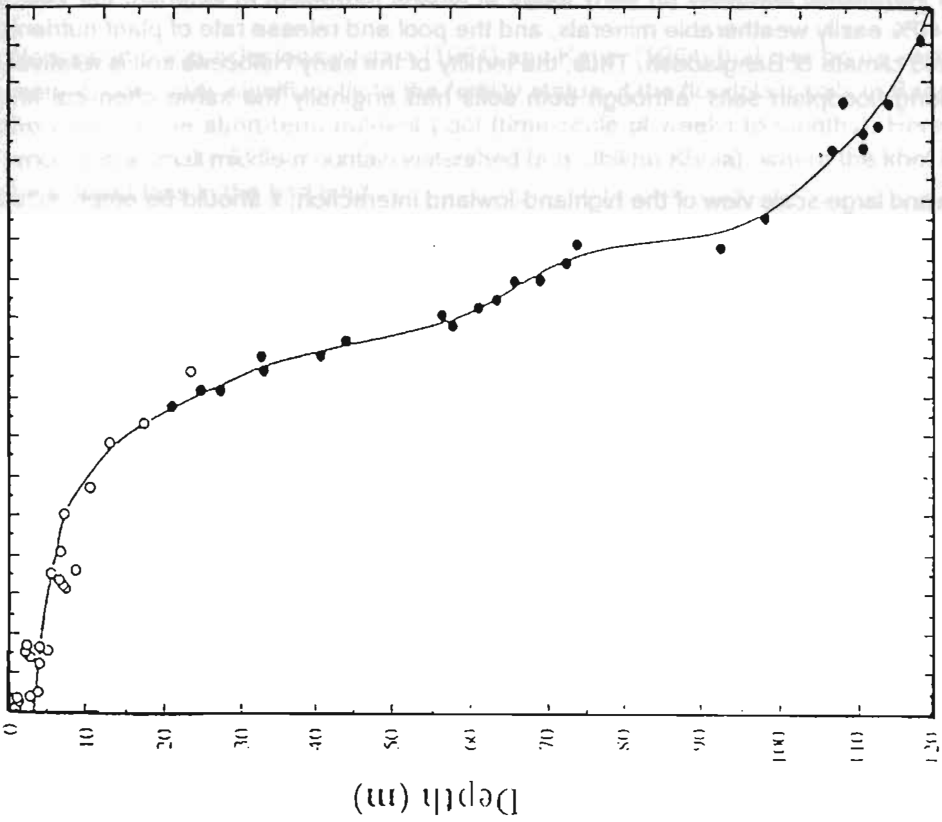
Figure 1. Schematic representation of the relationship between human and natural processes at three different scales (Ives, 1989).

2. Late Quaternary History, Sedimentation and Soils in Bangladesh: the Long-Term Effects.

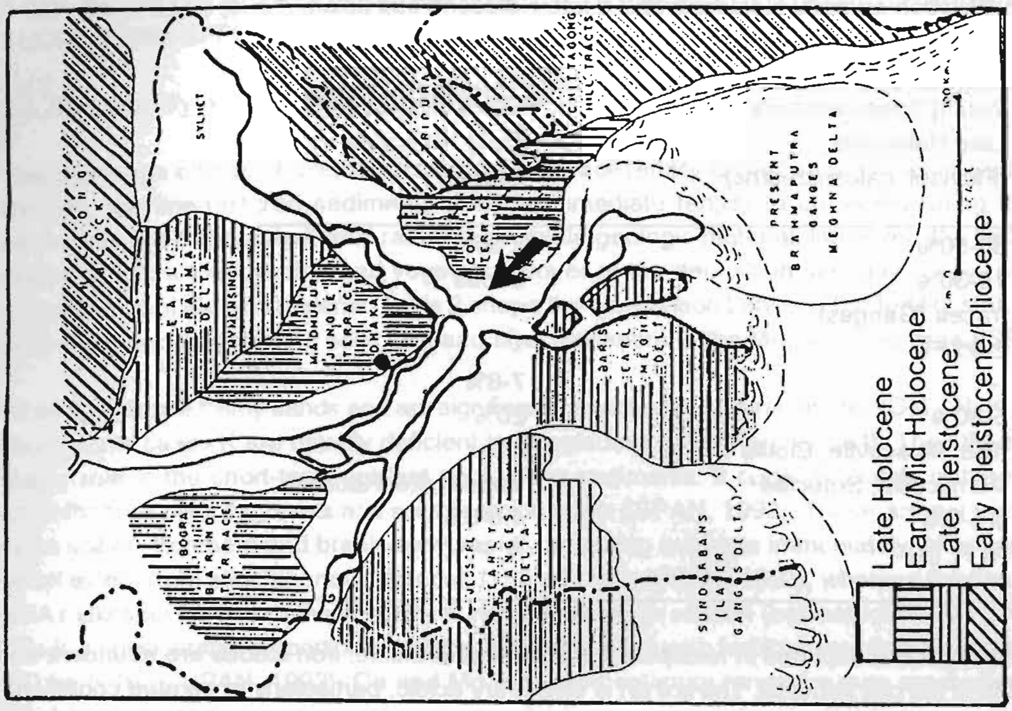
The delicate equilibrium between erosion and accumulation in the delta is mainly controlled by the level of the erosion baseline, which is the sea level in the Bay of Bengal. The global sea level changes and evolution of the delta complex during late Quaternary times is shown in Figure 2.

The sea level was 120 m lower 18,000 years BP ago than today. Regional differences of ±5 m are due to tectonic movement. The steeper topographic gradients in the river beds gave rise to large-scale erosion and dissection of the delta. When the sea level rose during the early Holocene (9000 - 8000 yr BP), most of Bangladesh was under water, and the coastline was at the Rajmahal hills in the Assam Province of India (Rana, 1993). A new delta complex accumulated, particularly during the mid-Holocene, when the ocean reached the current water level, at about 5000 yr BP. Some compartments of the delta (e.g. the Madhupur terrace) were lifted up and taken out of the active accumulation zone due to Holocene tectonic activity (Rana 1993; MPO, 1995). The deposition of young sediments continued in the area of the current river courses all through the late Holocene period and up until today.

We conclude that the interaction between global climate and sea level changes, regional tectonic movement and local topography dominate the pattern of sediment accumulation in the floodplain over time. It further implies that the landscape and the soils in the entire delta started with exactly the same substrate in terms of geology and mineralogy as today. According to the different ages of the various delta compartments, we find different stages of weathering, soil development and fertility levels in the soils. This in turn has wide implications on the cropping pattern and the productivity of land. Table 1 shows a comparison between an early Holocene-late Pleistocene (MPO, 1985) red soil in the Madhupur tract and a late Holocene floodplain soil in the Ganges/Brahmaputra area.



Barbados sea level curve (Fairbanks 1989, *Nature* 342)



Quaternary Deltaic Arcs in Bangladesh (Schematic)
after MPO 1985

Site of the ISPAN (1993) study

Figure 2. Barbados sea level curve and quaternary delta arcs in Bangladesh.

Table 1. Comparison between an early Holocene and a late Holocene soil (Islam, 1964; UNDP/FAO, 1971; MOP, 1985).

Mineralogy	Young floodplain soils Late Holocene (Fluvisol, calcaric/eutric)	Old floodplain soils Early Holocene Latosol
Quartz	30-50%	< 30%
Feldspars	15-30%	traces
Carbonate	traces (Ganges)	-
Heavy minerals	2-9%Fe	-
Fe-oxides	-	7-8%
Micas	5-30%	20%
Clay -Minerals	Illite, Muscovite, Biotite Vermiculite, Smectite	Illite Vermiculite, Kaolinite
pH	5.5-8.5	4.6-6.5
deficiency	N, P, (K)	N, P, K

The early Holocene latosols are depleted in feldspars, muscovite and biotite; iron oxides are abundant and Kaolinite makes up 60% of the clay minerals. The soil pH is often very acidic, particularly in aerated conditions. However, the presence of vermiculite suggests an early stage of latosol formation. In contrast, the young floodplain soils contain 25-40% easily weatherable minerals, and the pool and release rate of plant nutrients is high in the warm and humid climate of Bangladesh. Thus, the fertility of the early Holocene soil is relatively poor compared to the young floodplain soils, although both soils had originally the same chemical and mineralogical composition.

With regard to the long-term and large-scale view of the highland-lowland interaction, it should be emphasized that a constant supply of sediments is transported into the floodplain (estimated time-scale in the order of 10^2 to 10^3 yr). We find young, fertile fluvisols that are not in equilibrium with the warm/humid tropical climate in Bangladesh instead of the expected low-fertility latosols. This is one important and beneficial aspect in the discussion of floods and sedimentation. Yet the immediate fertilizing effect of the young sediments has to be documented. Furthermore, the riverborne sediments consist of materials that originate both from geological processes like landslides (e.g. feldspars, micas and olivine) and pedogenesis (e.g. smectites and organic matter). However, it is difficult to identify the source of these materials (highland versus lowland). Are the deposits eroded sediments from the floodplain itself?

In summary, the sedimentation in the floodplain plays an important role in fertility, and crop production seems to be dominated by a combination of natural processes on the global (sea level changes) and regional scales (tectonic movement). Human impact seems to be insignificant at this level of scale. These conclusions support the hypothesis by Ives and Messerli (1989) which suggests that the long-term and large-scale processes dominate the sediment processes in the delta. However, we have to oppose the above mentioned long-term view to the short-term dynamics of sedimentation and accumulation in order to get a more comprehensive view of the processes during the last decades.

3. THE FERTILITY STATUS OF SEDIMENTS, THE DYNAMICS OF EROSION AND ACCUMULATION: THE SHORT TERM EFFECTS

3.1. The Quality of the Sediment Deposition

The short-term effects of riverborne sediments on soil fertility is best seen immediately after their deposition. Usually, the fine-textured sediments provide immediate fertility to crops indicating that the accumulated sediments are transported soils rather than sterile geologic material. However, the texture of the deposited material, micro-topography, and vegetation cover at the deposition site play a key role in determining the nutrient value of the new material. Table 2 shows the comparison between the fertility status of fresh riverborne sediments and surrounding soils (pre and after monsoon) in the Meghna river area (ISPAN, 1993).

All sediments are loamy sands and are significantly enriched in organic matter (OM), N, K, S, and Mn. Nitrogen and in some cases K are usually deficient in Bangladesh soils (Karim, 1964). The OM is suggested to play a major role in the short-term nutrient pool of the sediments. It consists mainly of blue-green algae (BGA), allochthonous plant fragments and soluble amino acids (ISPAN, 1993). These are not very stable components in the soil environment and break down rapidly releasing nutrients immediately. Nitrogen originates only to a small extent from allochthonous sources (150 g N ha^{-1}, ISPAN, 1993), whereas fixation of atmospheric N by BGA makes up the bulk of the N supply during the monsoon season (estimated 16-20 kg N ha^{-1}, ISPAN, 1993) This is a considerable proportion of what is usually applied with fertilizer for High Yielding Variety (HYV) crops (60 kg N ha^{-1}, ISPAN, 1993). Ca and Mg are in the optimum range for crop production in most soils in the Meghna river area.

We support the conclusion by Islam (1964) and Karim (1964) that riverborne sediments, especially their OM content, contribute significantly to the fertility status of the floodplain soils in Bangladesh. This is particularly the case for the short-term nutrient pool (time-scale of weeks to months). Here, we see similarities to the process in a small middle-mountain watershed (e.g. Jhikhu Khola), where the khet land benefits annually from the nutrient loss in the bari land.

Table 2. Fertility status of fresh riverborne sediments compared to the residual soil premonsoon and surrounding soil after one cropping season (ISPAN, 1993).

	Premonsoon	Sediments	Postmonsoon
OM [%]	3	5.1	2.6
pH	5.6	6.3	5.3
N [μg/g]	23	193.8	18.4
Ca [meq/100g]	10.3	12	11
Mg [meq/100g]	4.4	4.5	2.3
K [meq/100g]	0.18	0.44	0.21
P [μg/g]	17.1	19.8	23.6
S [μg/g]	31.1	156.8	51.7
B [μg/g]	0.4	1.0	0.8
Fe/ [μg/g]	616	706	838
Cu [μg/g]	10.9	6.1	4.5
Mn [μg/g]	78.4	427.3	50.2
Zn [μg/g]	3.5	3.8	4.3

This is, in fact, conventional wisdom which unfortunately is not sufficiently recognized and more documentation of this process is needed when discussing flood protection and construction of embankments. The effect of such action on the sustainability of soil fertility for crop production needs to be given more attention. However, the current demand for plant nutrients is dramatically increasing due to land use changes, induced by triple cropping patterns and cultivation of HYV crops. The high nutrient demand by these crops and rotation systems overrides the natural fertilizing effect of the sediments, and high amounts of fertilizers are required to sustain productivity of the soils.

3.2. Erosion and Accumulation in the Floodplain: Where do the Sediments Come From?

The origin of the sediments is a major question in the debate of highland-lowland interactions in the Himalayas. Does soil erosion in the Himalayan Middle Mountains contribute to soil fertility in Bangladesh?

Changes in the floodplain river courses can give an idea about the dynamics of erosion and accumulation of sediments in the floodplain itself. Figure 3 shows a section in the Brahmaputra (Jamuna) area with the riverbed 1973 and 1993 as it was mapped based on LANDSAT images.

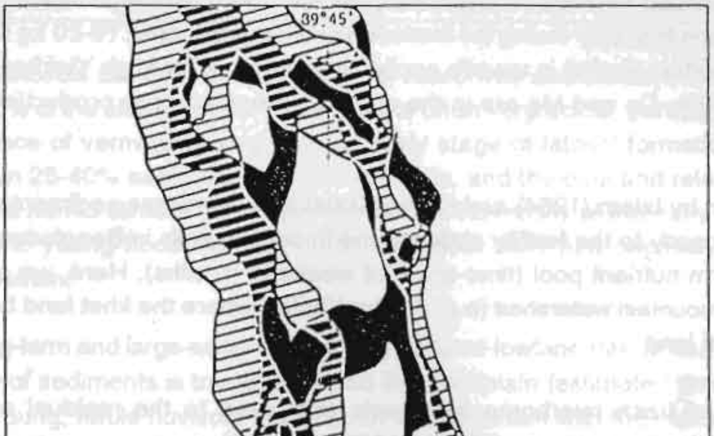


Figure 3. Riverbed of the Brahmaputra/Jamuna 1973 and 1993.

The comparison indicates that the Jamuna river has been displaced by some 60 m / yr^{-1} during the last 30 years. In some places, a displacement of 800 m yr^{-1} is common (Wahed, 1993; Rana, 1993). Such massive year-by-year river erosion and mobilization of sediments in the floodplain itself suggests that the suspended material in the river likely originates from locally or regionally transported soil, rather than material directly transported from the mountains. Here, it is important to note that this view refers to the short-tern dynamics of the system. In the long-term, however, all the material ultimately originates from the Himalayas, but the transportation rate, the distances of and time requirements for transport, and the origin of the material is widely unknown.

4. CONCLUSIONS

The deposition of young sediments in the floodplain of Bangladesh is extremely important with regard to the short-term and the long-term nutrient pool of the soils. A similar observation was made in the small watershed of the Jhikhu Khola, pointing out that some of the highland-lowland processes are comparable regardless of the scale of the landscape under consideration.

Ultimately, the sediments originate from the Himalayas. However, looking at the short- to medium-term process of erosion-accumulation in the floodplain itself, the regional transport of sediments is likely dominating. Sediment transport in the floodplain is mainly controlled by natural factors at different temporal and spatial scales, while the Quaternary history and sea level changes act at the global scale, and tectonic movement at the regional scale. Human impact on the macro level seems to be considerably less important than the natural processes. There is a fundamental difference in these processes at the micro-level of the Jhikhu Khola where the human influence is likely dominating. We support the view by Ives and Messerli (1989) that the relationship between human and natural impacts on processes changes with the different scales under consideration.

We learned from the Jhikhu Khola watershed that the micro-scale response to human impact is sensitive. From the Bangladesh floodplain, we learned how nature controls the large-scale processes in the highland-lowland interaction. However, we are at present unable to understand the link between these opposing positions. There is an urgent need to connect both scales and in our opinions, an understanding of the meso-level processes is the only way to address this complex question. As long as we do not understand the transfer functions from the micro- to the meso- and to the macro level, we are not able to comment on the highland-lowland interactions. Until such research results are available, many questions relating to the 'Himalayan Dilemma' remain unanswered.

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