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Impact of reduction in upstream fresh water and sediment discharge in Indus deltaic region

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Abstract

The Indus river basin stretches from the Himalayan Mountains in the north to the dry alluvial plains of Sindh in the south. The area of Indus basin is 944, 574 sq. km.The development of infrastructure in the basin affected the sediment and water discharge downstream of Kotri Barrage. Prior to the construction of major dams and barrages on the Indus River the recorded average of sediment and water discharge downstream Kotri Barrage was 193 million ton/year and 107 billion m3/year respectively. Reduction in sediment and water discharge is causing coastal erosion in the Indus deltaic and coastal areas and resulting in significantly high levels of sea water turbidity rendering the water quality of coastal waters unsuitable for a number of marine organisms. The turbidities of the seawater influence the bottom limit of light penetration in the sea thus controlling the primary productivity in the coastal and creek waters. The anthropogenic impact of upstream water and sediment blockage has resulted in the shrinkage of active delta and stunted growth of mangrove forest. The beleaguered delta has been forced to face severe problem of coastal erosion due to unplanned coastal development in the area.

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Introduction

The Indus River, about 3000 km long, is one of the largest and most important river systems of the world, and predominantly flows through Pakistan towards the western margin of the India-Pakistan subcontinent (Figure 1). It is not only one of the oldest rivers existing today, but has also cradled one of the oldest and historically important civilizations on the earth, and is a life-line for the human consumption and agriculture of Pakistan. The Indus River is draining one of the highest and most tectonically dynamic regions of the world i.e., western Tibet and Himalaya and Karakoram and is fed by the rains of the SW Asian monsoon. The flux from this river has produced a vast sediment body 'the Indus Fan' in the Arabian Sea ~5 x 106 km^3 (Naini & Kolla 1982), second only to the Bengal Fan in size. The Indus river basin stretches from the Himalayan Mountains in the north to the dry alluvial plains of Sindh in the south. The area of Indus basin is 944, 574 sq. km (Asianics Agro-Dev. International (Pvt) Ltd., 2000) making it the 12th largest among the rivers of the world (Figure 1).

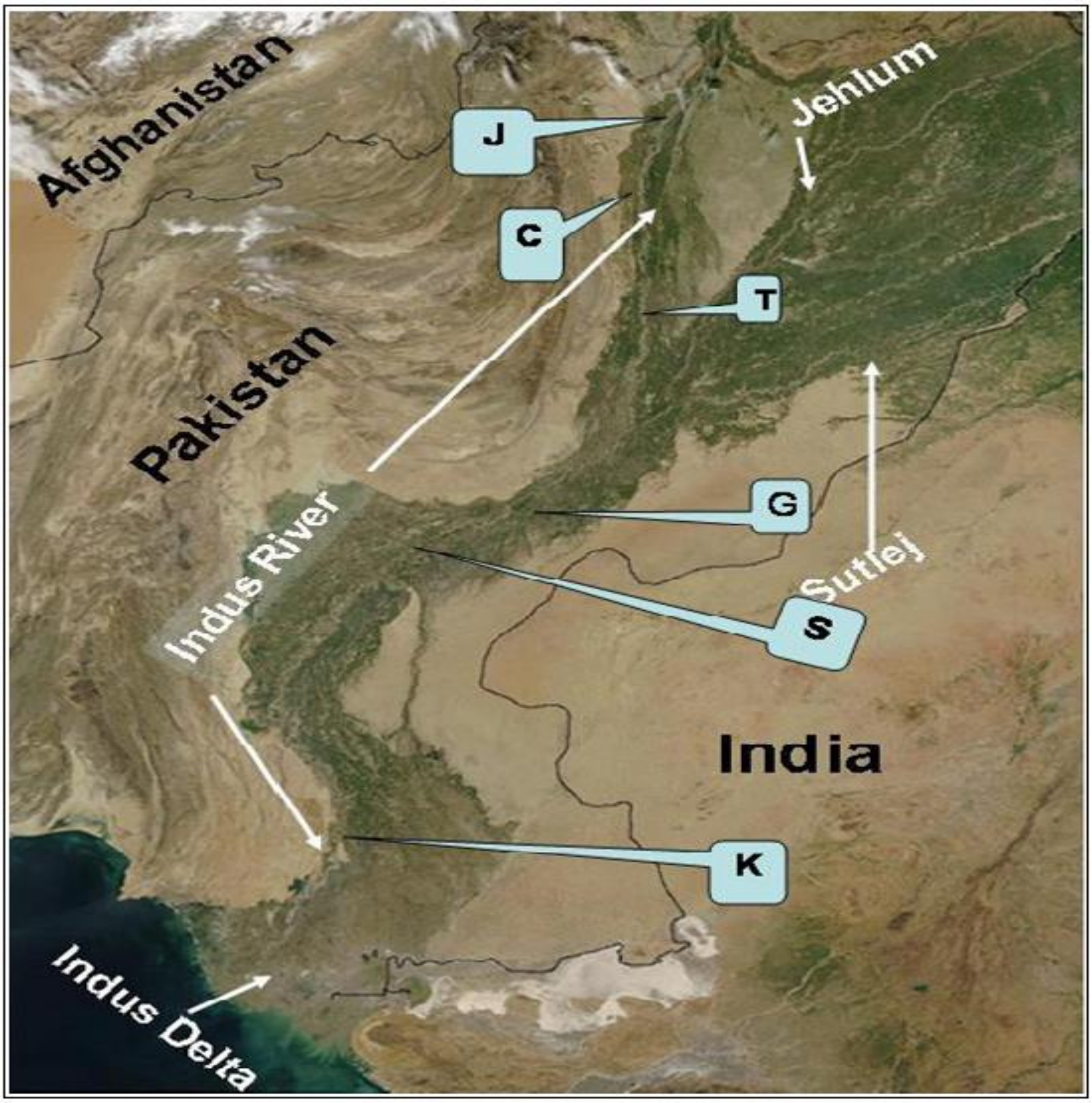

Fig. 1. Satellite image of Indus River and its delta. Major barrages over the Indus River are marked as K (Kotri), S (Sukkur), G (Guddu), T (Taunsa), C (Chashma) and J (Jinnah) (Satellite Image Source: NASA).

Its deltaic area is 3 x 104 km2, ranking it 7th in the world. The Indus ranks at number four amongst the world's rivers in having a wave power at the delta shoreline of about 13 joules/sec/unit crest width and 1st in having a wave power at a distance from the shoreline at which the water depth reaches 10 metres of about 950 joules/sec/unit crest width (Pakistan Water Gateway, 2003). The Indus basin was one of the world's premier water laboratories in the late twentieth century. The water system of the Indus dates back six millennia to the Harappan period and continuing through Hindu, Buddhist, medieval, Islamic, and colonial periods. However, the last six decades have seen the greatest developments and large scale management of the water system.

At the mouth of the Indus, east of Karachi the modern Indus River Delta has formed during the Holocene. Unlike deltas of many other rivers, the Indus Delta is composed of clay and infertile soils. Much of the modern delta plain is very arid, with swampy area restricted to the immediate areas of tidal channels and the coastal tidal flood plains. Seasonal and annual river flows in the Indus River system are highly variable (Warsi, 1991; Kijine *et al*., 1992; Ahmad, 1993). The largest flow from the Indus occurs between June and late September, driven by the summer monsoon season and a peak in the flow from snow melt (from the mountains) that increases the discharge of water along with the eroded sediments. These waters are used primarily for irrigation of agricultural crops and dams have been constructed to provide flood control and hydroelectricity.

Damming of the indus river

Pakistan depends on irrigation and water resources for 90% of its food and crop production (World Bank, 1992). The irrigation system in Pakistan is comprised of three major storage reservoirs, 19 barrages or head works, and 43 main canals with a conveyance length of 57,000 km, and 89,000 water courses with a running length of more than 1.65 million kilometers (Table 1). Today, it is estimated that up to 60% of the Indus water is used to feed Pakistan's irrigation networks, and that the Indus watershed irrigates up to 80% of Pakistan's farmland (Iftikhar, 2002). Pakistan's vast irrigation system feeds more than 150,000 Km2 of farmland, with the highest irrigated to rain-fed land ratio in the world. This vast irrigation system feeds more than 162,000 Km2 of land in Pakistan, a country with the highest irrigated and rain-fed land ratio in the world, 4:1. About 180,000 km2 (~6.6% of the global irrigated area) is presently being irrigated in Pakistan. The contribution of rainwater to crops in the Indus Basin Irrigation System is estimated at about 16.5 billion m3/year (Ahmad, 1993).

The development of infrastructure in the basin affected the sediment and water discharge downstream of Kotri Barrage (Figure 2). Prior to the construction of major dams and barrages on the Indus River the recorded average of sediment and water discharge downstream Kotri Barrage was 193 million ton/year and 107 billion m3/year respectively (Table 2). As expected the major decline in the sediment and water discharge occurred after the commissioning of Mangla dam (in 1967) and Terbela dam (in 1976). From 1998 onwards the sediment and water discharge below Kotri Barrage has declined at an alarming pace mainly due to low rain fall. The overall impacts of man-made changes in the Indus River system are best observed downstream Kotri Barrage where prior to the construction of the barrage there were no days without water discharge (Figure 3). Zero flow days were observed during the post-Kotri period (1962–1967).The occurrence of zero flow days progressively increased following the commissioning of the Kotri and Guddu barrages and the Mangla Dam (Asianics Agro-Dev. International (Pvt.) Ltd., 2000). In the post-Kotri period (1961-1967), the maximum number of days with zero flows was 100. This increased to around 250 days in the post-Kotri and post-Mangla period (1967-1975). The present situation is much more alarming because of below average rain fall in the Indus River catchment area. Presently there are only two months (August-September) in a year when the Indus River flows downstream Kotri Barrage.

The amount of water in the Indus River has decreased dramatically from around185,000 million m3 per annum in 1892 to 12,300 million m3 per annum in the 1990s (Iftikhar, 2002). Little freshwater now reaches the lower Indus. As a result the floodplains and wetland ecosystems of the Delta have been severely degraded.

Study area

There are 17 major creeks making up the original Indus delta, but due to reduced flows downstream of the Kotri barrage, only the Khobar Creek now receives water from the Indus (Figure 1). Due to lack of environmental awareness any releases of water to the Indus Delta were considered as wasted. The Indus Delta itself was seen as a wasteland of mudflats, creeks and mangroves. The Indus Delta is subjected to the highest average wave energy of any major delta in the world (Wells and Coleman, 1984). This is mainly due to the intense monsoonal winds which produce high energy levels. The Indus River is currently contributing hardly any sediment to the delta causing shrinkage as the active delta is now only 1200 km2 in area compared to the 6200 km2 before the construction of series of dams and barrages on the Indus River (Asianics Agro-Dev. International (Pvt.) Ltd., 2000). Consequently, there has been intrusion of sea water upstream of the delta, at places extending up to 75 km in the coastal areas of Thatta, Hyderabad and Badin districts. The twin menace of almost total absence of fresh water in the river downstream ofKotri and heavy sea water intrusion from the delta has destroyed large areas of prime agricultural land, including submersion of some villages in the coastal belt of these districts. In turn this has caused desertification and displacement of several hundred thousand local residents who had been living there for many generations. An extreme level of wave energy and little or no sediment contribution from the Indus River is transforming the Indus Delta into a true wave dominated delta and development of sandy beaches and sand dunes along the former deltaic coastline is underway.

Results and discusion

Agriculture Runoff, Water Logging and Salinity

The topography of Sindh is more or less flat so that the natural flow of the drainage is gradual, allowing rapid increase in ground water table. The prevalent canal irrigation system has resulted in large scale water logging and salinity problems. Approximately 60% of the aquifer underlying the Indus Basin is of marginal to brackish quality. The problem of water logging and salinity became apparent in the late 1950s. In lower Indus basin, the area with a ground water depth less than 3 meters was 57%.

Table 1. Major dams and barrages constructed on the Indus River system.

Structure	Year of Construction with maximum discharge capacity
Tarbela Dam	Constructed in 1976.
Mangla Dam	Constructed in 1967.
Ghazi Barotha Hydro Power Project	Recently completed with a capacity of 500,000 cusecs.
Jinnah Barrage	Constructed in 1946 with a design discharge capacity of 950,000 cusecs.
Chashma Barrage	Chashma Barrage was constructed in 1971 with a design discharge capacity of 1.1 million cusecs.
Taunsa Barrage	Constructed in 1959 with a design discharge capacity of 750,000 cusecs.
Guddu Barrage	Constructed in 1962 with a design discharge capacity of 1.2 million cusecs.
Sukkur Barrage	Constructed in 1932 with a design discharge capacity of 1.5 million cusecs.
Kotri Barrage	Constructed in 1955 with a design discharge capacity of 875,000 cusecs.

To mitigate the menace of rising ground water and the associated problem of water logging and salinity, a network of drainage canals was constructed within the Indus Basin to drain ground water directly into the Arabian Sea. The drainage system has been less effective due to low gradient/flat topography and has in fact resulted in the intrusion of sea water to about 80km upstream (Panhwar, 1999). Sea water intrusion is much worse during the southwest monsoon (Figure 4).

Figure 4: Sea water intrusion through the network of canals constructed for the discharge of saline ground water to the sea.

Table 2. Changes in the sediment and water discharge downstream Kotri Barrage with time (Source Irrigation Department of Pakistan).

PERIOD	Water discharge (billion m3/year)Average	Sediment discharge Million ton/year Average
1931-1954	107	193
1955-1962	126	149
1963-1967	72	85
1968-1976	47	82
1977-1997	45	51
1993-2003	10	13

Sea level rise

The historical recorded data on sea level rise at Karachi and adjoining Indus Deltaic area is based on the data collected over the past 100 years, is 1.1 mm/year and it is expected to be more than double during the next 50 to 100 years, resulting in 20-50 cm rise in sea level (UNESCAP, 1996).

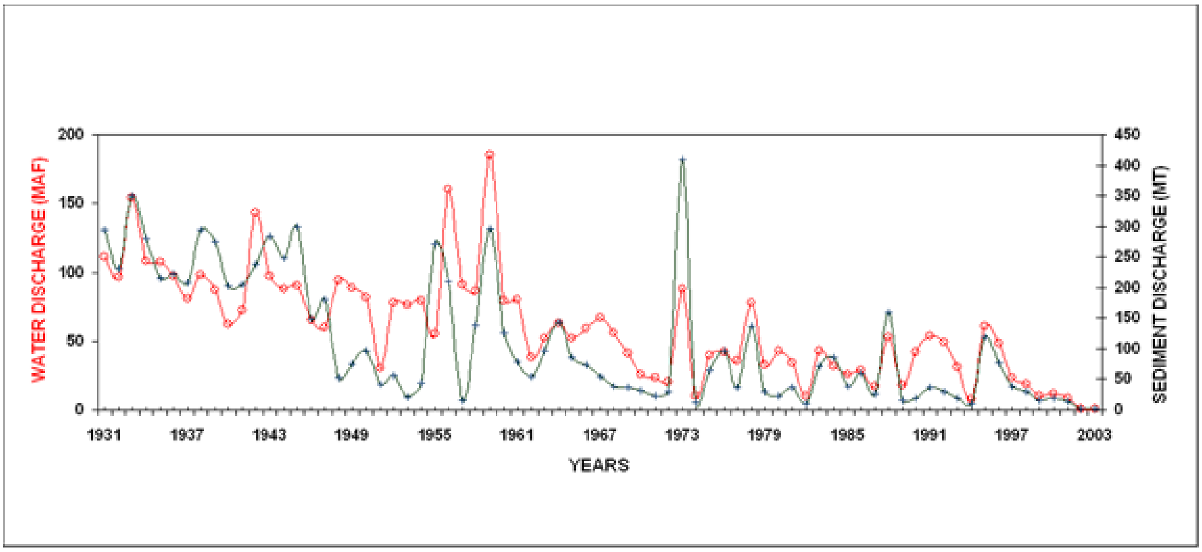

Fig. 2. Variation in the sediment and water discharge downstream Kotri Barragesince 1930 (modified from Milliman *et al.* 1984).

The adverse effect of sea level rise on the Pakistan coast is expected to be pronounced in the Indus Delta. A sea level rise of about 2 metres is expected to submerge or sea encroach an area of about 7,500 sq km in the Indus Delta.

There are no direct measurements available on subsidence rates in the Indus Delta, however, experience in other deltas indicate that subsidence rates at the delta must have increased due to lack of sediment flux.

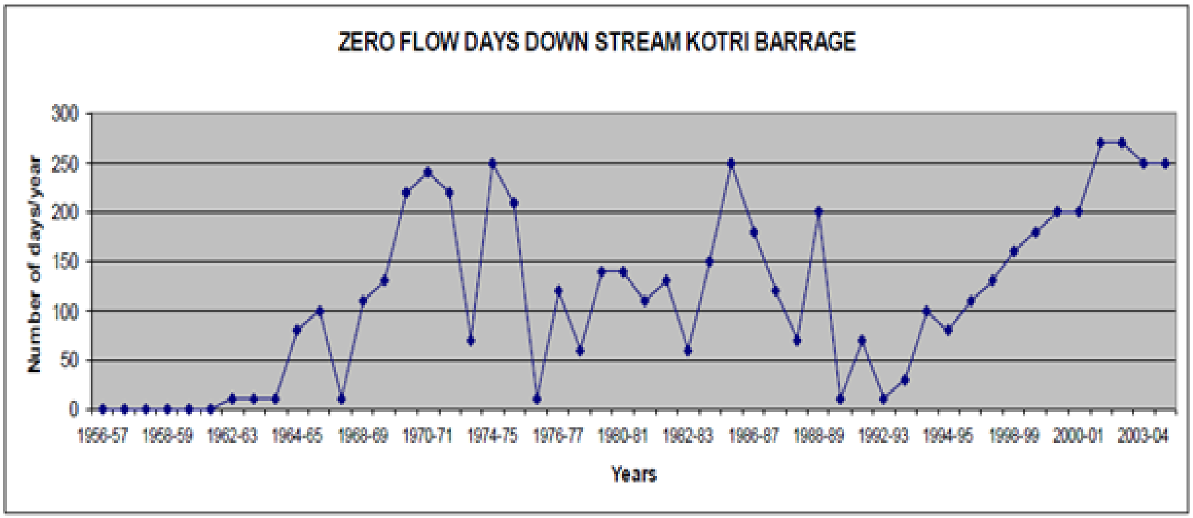

Fig. 3. Dramatic rise in the days with no river flow downstream Kotri Barrage with the construction of dams and barrages on the Indus River (modified after Asianics Agro-Dev. International (Pvt.) Ltd., 2000).

Indus Delta could experience a relative sea level rise of up to 8 to 10mm/yr as per the projected rate of global component of sea-level rise of up to 6mm/yr in the next century. If the present trends continue the Indus Delta will ultimately establish a transgressive beach dominated by aeolian dunes, due to lack of sediment inputs and high energy waves (Haq 1999).

Impact of water shortage on mangroves

The Indus delta has about 1600 Km2 of mangroves forests; of these about 500 Km2 can be classified as dense mangrove stands. The shortage of rainfall, the high evaporation rate and the decreasing flows of freshwater down the Indus as a result of dams and barrages means that salinity levels in the creeks often exceeds that of sea water.

Fig. 4. Sea water intrusion through the network of canals constructed for the discharge of saline ground water to the sea.

Even as mangroves are generally able to survive in sea water without regular freshwater input, it is unlikely that they will succeed indefinitely. Apart from longer-term threats to the survival of Indus delta mangroves, there are pressures from over grazing and lopping for fuel wood, which result in stunted trees in some areas (Figure 5). Because the lives of local people are closely linked to the natural resources of the Delta ecosystems, each environmental impact has a social impact. Local communities are dependent on natural resources for their livelihood, including floodplain forests, mangrove forests and fishes.

The human population in and around mangrove forests on the Sindh coast is estimated to total 1.2 million people, nearly 900,000 of whom reside in the Indus Delta (Salman 2002). Of these, a predominantly rural population of more than 135,000 depends on mangrove resources for their livelihoods (Shah, 1998). Reductions in freshwater inflows have had tangible impacts on mangrove ecology, and on the fish populations that rely on them for breeding and habitat.

Fig. 5. Destruction of mangrove forest in the deltaic area near Karachi.

At least three quarters of the Delta's rural population depend, directly or indirectly, on fishing as their main source of income, and most of Pakistan's commercial marine fishery operates in and around the mangrove creeks on the coast of Sindh Province. A large proportion of fish and crustaceans spend at least part of their life cycle in the mangroves, or depend on food webs originating there (Meynell & Qureshi 1993).

Coastal erosion

Reduction in sediment and water discharge is causing coastal erosion in the Indus deltaic and coastal areas and resulting in significantly high levels of sea water turbidity rendering the water quality of coastal waters unsuitable for a number of marine organisms. The turbidities of the seawater influence the bottom limit of light penetration in the sea thus controlling the primary productivity in the coastal and creek waters. The higher turbidities also influence the distribution of marine organisms particularly the fish and shrimp in the coastal waters. The higher turbidities are not tolerated by filter feeding benthic organisms and hence they are usually absent in the areas which are affected by coastal erosion. The major impacts of turbidities on the marine environment is smothering of benthic fauna particularly filter feeding organisms, and the reduction of photic zone bylimiting light penetration, resulting in reduced primary productivity. The lower visibility in the seawater also influences the feeding, and migration of fish and shellfish. It is generally believed that the higher turbidities in the coastal waters due to southwest monsoon winds during June - September period induces fish and shrimp stocks of coastal waters to migrate into deeper waters. The extent of this problem is increasing due to the increase in the sea encroachment in the area. The turbidity of the water in the Indus Delta varies spatially and seasonally.

Turbidities are also influenced by the strong tidal flux which reverses its direction during ebbing and flooding. Generally the turbidities are higher during ebb tides, particularly in the shallow creeks. The turbidities are also high within the delta area and in the adjacent coastal waters during river runoff after the raining season of southwest monsoon.

The turbidities in terms of transparency of sea water (Secchi disc disappearance depth) can also provide insight to the extent of the turbidities in the Indus Delta. The maximum water transparency in the major creeks of the Indus Delta are 2.5-4.5m in the Gharo creek, 3.0-5.0m in the Phitti Creek and 7.0m in the offshore water during the Jan-Feb period. The minimum values (0.5-1.0m) of sea water transparency in the Gharo/Kadiro creek, <0.2m in the Phitti Creek and 0.2m to >2.0m in offshore area adjacent to the creeks, during the May to August period. The turbidities in the offshore waters adjacent to the delta are higher during southwest monsoon period than during the rest of the year.

Conclusion

The anthropogenic impact of upstream water and sediment blockage has resulted in the shrinkage of active delta and stunted growth of mangrove forest. The beleaguered delta has been forced to face severe problem of coastal erosion due to unplanned coastal development in the area. The wellbeing of Indus Delta demands a realistic assessment of the minimum quantity of fresh water and sediments required to prevent total disappearance of the delta. There is need for a certain amount of water and sediment to be discharged in to the delta on year round basis. It is also important that the management of the delta should become a part of an integrated coastal zone management in a holistic manner to consider not only the coast but the whole eco-system, from the source to the catchment area, as well as the delta.

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