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Climate change and role of anthropogenic impact on the stability of Indus deltaic Eco-region

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Abstract

The Indus River is one of the major river systems of the world and the principal contributor in the creation of the Indus Fan - second largest sediment body in the ocean basins, to talling ~5 x 10^6 km^3. Recent geological and geophysical information obtained from the Pakistan margin suggests that the Indus River and Fan system was initiated shortly after India-Asia collision at ~55 Ma. The Indus River, is currently contributing a fraction of fresh water or sediment in to the Arabian Sea. Consequently, the seawater intrusion has resulted in tidal intrusion in the prime agricultural land in the Indus Deltaic region. Extensive use of fresh water for irrigation in recent years has caused a decline in the down stream discharge of the Indus River. Construction of barrages, dams, and link canals has further reduced the freshwater flow downstream Kotri Barrage from 146 MAF/year to less than 10 MAF/year. In the northeast monsoon period Indus River has practically zero discharge below Kotri Barrage. As a consequence, the river below Kotri shows increased braiding and sand bar development. Sediment passing down the system tends to be deposited in the section south of Kotri, rather than maintaining the growth of the delta. As a result the Indus Delta that used to occupy an area of about 6,180 km^2 consisting of creeks, mudflats and mangrove forest is now reduced to 1,192 km^2 since the construction of dams and barrages on the Indus River. Pakistan like other parts of the world is also facing a problem associated with sea level rise along with related issues such as coastal erosion and inundation. The analysis of historical tidal data shows that Pakistan coastal sea level has risen in the same way as the global sea level due to global climate change. Besides eustatic sea level rise, the dominance of local factor like subsidence of land may be a catastrophe for low-lying areas. Indus Delta could experience a relative sea level rise of up to 8-10 mm/yr as per the projected rate of global component of sea-level rise of up to 6 mm/yr in the next century. To mitigate the impacts of rising ground water and associated problem of water logging and salinity, a network of drainage canals was constructed down in the Indus Basin to drain saline ground water into the Arabian Sea. The drainage system has been less effective due to low gradient/flat topography and it has in fact resulted in the seawater intrusion into the link canals up to about 80 km upstream.

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Introduction

The Indus River is one of the major river systems of the world and the principal contributor in the creation of the Indus Fan - second largest sediment body in the ocean basins, totalling ~5 x 10^6 km^3. Recent geological and geophysical information obtained from the Pakistan margin suggests that the Indus River and Fan system was initiated shortly after India-Asia collision at ~55 Ma (Clift *et al.*, 2001).

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).

The Indus drains the arid to semi-arid Western Himalaya Mountains with headwaters at elevation greater than 4000m. Most of the runoff generated in the Indus River catchment north of the Kalabagh comes from snow and ice melt. About 37% area in the Karakorams and 17% in the Himalayas is covered with glaciers (Tarar, 1982). The catchments of Jhelum and Chenab Rivers north of Mangla and Marala, receives the summer monsoons and thus, have a considerable rainfall component in addition to snow and ice melt. The Indus, Jhelum and Chenab rivers are the major source of water supply to the Indus Basin Irrigation System. At the mouth of the Indus, east of Karachi the large, swampy Indus River Delta is formed, which, unlike deltas of many other rivers, is composed of clay and infertile soils (Fig. 1).

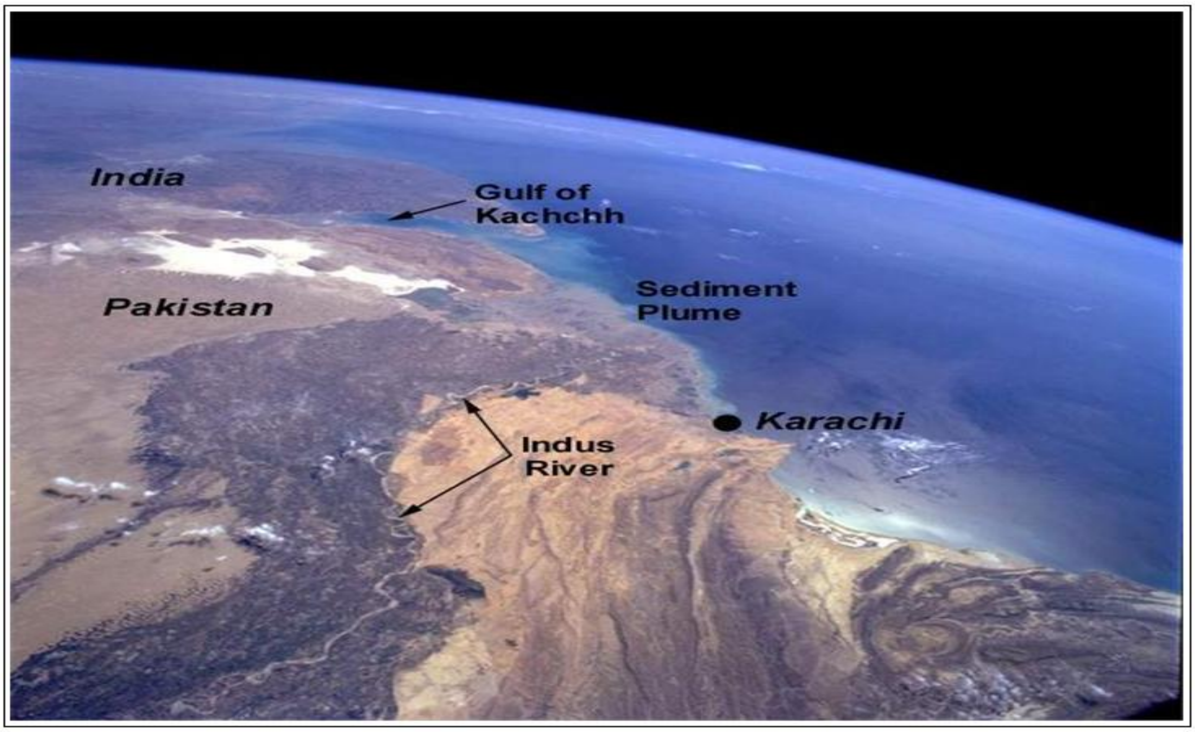

Fig. 1. Synoptic view of the Indus River and its delta.

Seasonal and annual river flows in the Indus River system are highly variable (Warsi, 1991; Kijine *et al.,* 1992; Ahmad, 1993).

The analysis of the daily and monthly flows also indicates a similar trend (Bhatti, 1999). The largest flow of the Indus occurs between June and late September, that relates to the summer monsoon season, at which point the snow melt (from the mountains) increases the discharge of water along with the eroded sediments. The waters are used primarily for irrigation of agricultural crops; dams have been constructed to provide flood control and hydroelectricity.

Anthropogenic and Natural Hazards to Indus Delta

The survival of Indus Delta is under serious threat. This paper highlights some of the most prominent anthropogenic as well as natural hazards *viz*. Dams and Barrages, Coastal developments, Un-planned dredging, and Agriculture Drainage, Water Logging and Salinity.

Dams and barrages

Pakistan depends on irrigation and water resources for 90 percent of its food and crop production (World Bank, 1992). Indus Basin Irrigation System (IBIS) is the largest contiguous irrigation system in the world developed over the last 140 years.

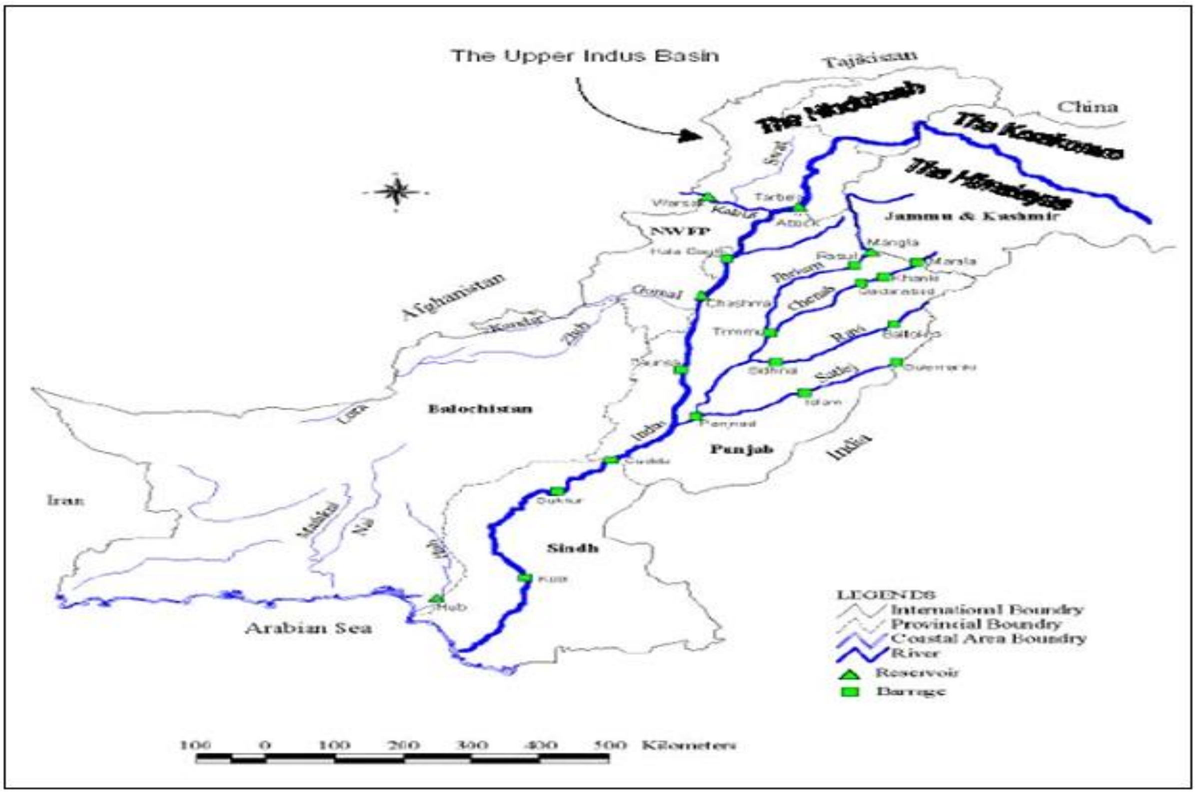

Fig. 2. Network of barrages and reservoirs on the Indus River (after Khan 2001).

The vast 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 kilometres, and 89,000 water courses with a running length of more than 1.65 million kilometres (Fig. 2).

This vast irrigation system feeds more than 40 million acres of irrigated land in Pakistan, a country with the highest irrigated and rain-fed land ratio in the world, 4:1. About 180,000 Km^2 (~6.6% of the global irrigated area) is presently being irrigated in Pakistan (FAO, 2001). The contribution of rainwater to crops in the IBIS is estimated at about 16.5 bcm (Ahmad, 1993).

Since all of the reservoirs and barrages on the Indus River were constructed without the environmental impact assessment (EIA) so there is little or no statistical and scientific data available which can give description of the baseline ecological conditions that can be compared to the present conditions. Therefore, it is extremely difficult to determine the direct effects of the construction of these structures against the background of changes occurring due to the irrigation and hydropower network as a whole, and other natural pressures upon the environment.

Pakistan's irrigation and water resource development has not been without environmental and resource degradation costs in all the ecosystems, i.e., mountains, plains, and the deltaic and coastal areas.

The construction of the barrages and the link and irrigation canals has, over the years, led to a systematic abstraction of water from the Indus. The Tarbela dam and Chashma reservoirs have resulted in the siphoning off 74 percent of Indus waters before it reaches Kotri Barrage, the last barrage point on the Indus in the southern Sindh province. The deltaic area has been estimated to have reduced from 3,000 square kilometres (km^2) to 250 km^2 (Hassan, 1992).

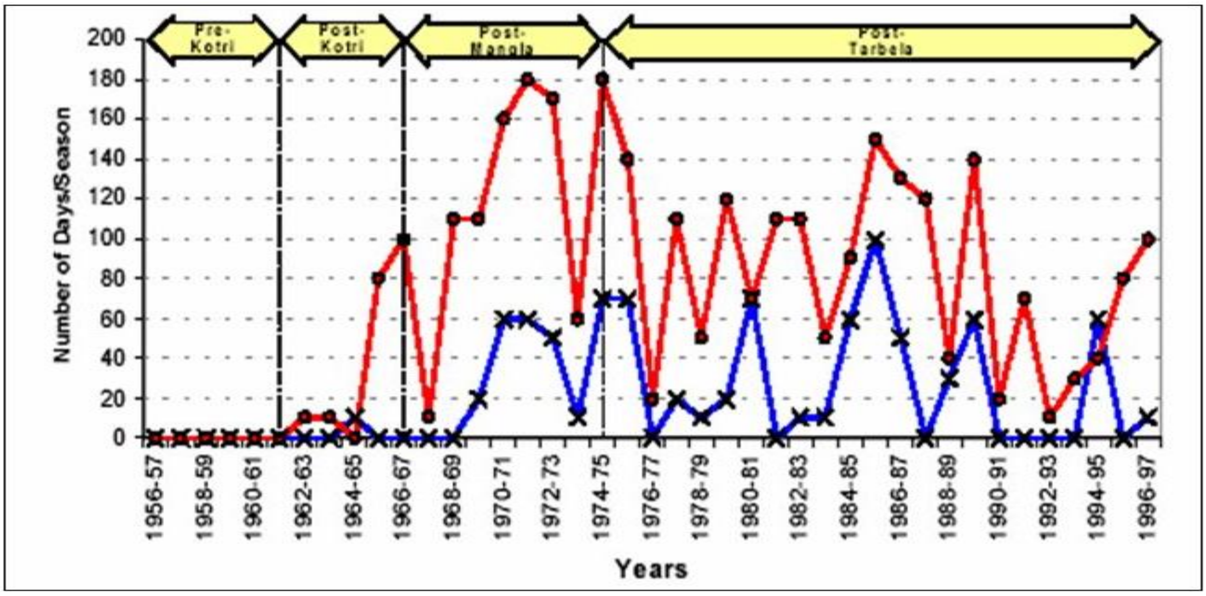

Fig. 3. Numbers of days per season with zero flow downstream Kotri Barrage (after Asianics Agro-Dev. International (Pvt) Ltd., 2000). Winter is marked with Red colour while summer is marked with blue colour.

Fig. 4. Villagers walking across the dried Indus River bed downstream Kotri barrage to search for the water.

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 (Asianics Agro-Dev. International (Pvt) Ltd., 2000).

The construction of Kotri barrage and the associated flood *bunds* restricted the distribution of freshwater in the delta and caused significant ecosystem changes that have been compounded by increased freshwater abstraction.

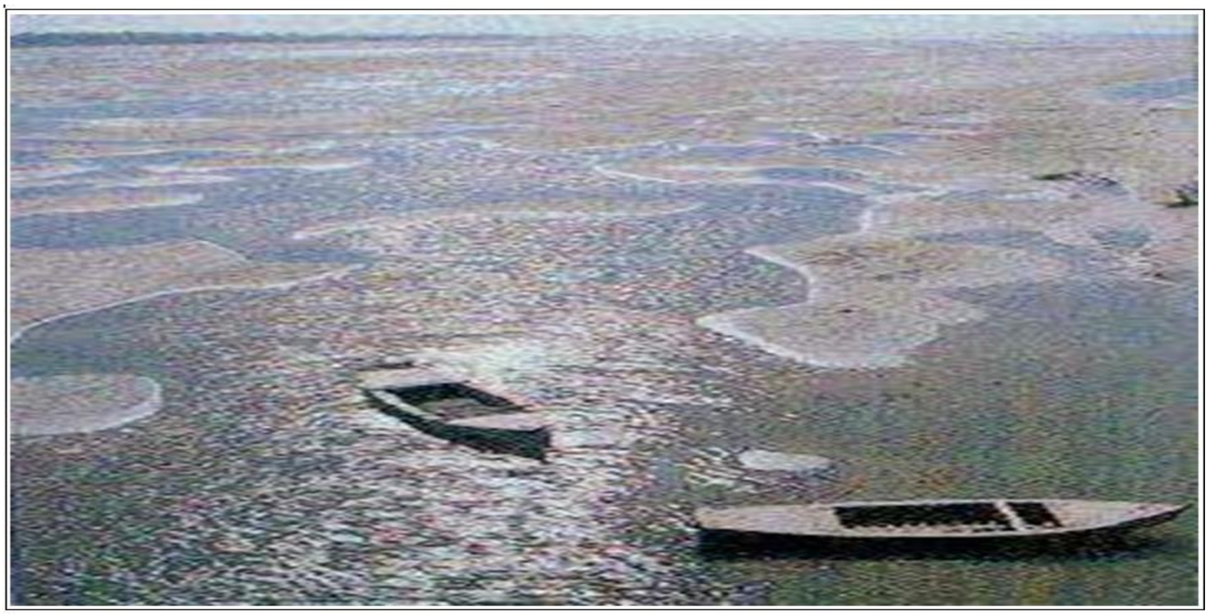

Fig. 5. Sand bar development downstream Kotri Barrage.

Fig. 6. Barrier Islands in the Indus Deltaic area south east of Karachi (NIO, 2001).

The development of infrastructure in the basin also affected the peak flows downstream of Kotri barrage. The highest peak flow of 27,787 m^3/sec was observed during the pre-Kotri period of 1955-61, whereas subsequently the highest peak flow recorded was 22,269 m^3/sec during the post-Kotri period of 1975-98 (lower by 20%).

The peak flow corresponding to the mean annual event reduced by 42%, which will have a direct impact on the inundation of the riverine areas. The annual variability was extremely high. The minimum and maximum peak flows of 12,513 and 27,787m^3/sec were observed during the pre-Kotri period, respectively, having a ratio of minimum to maximum peak flows of 1:2.2.

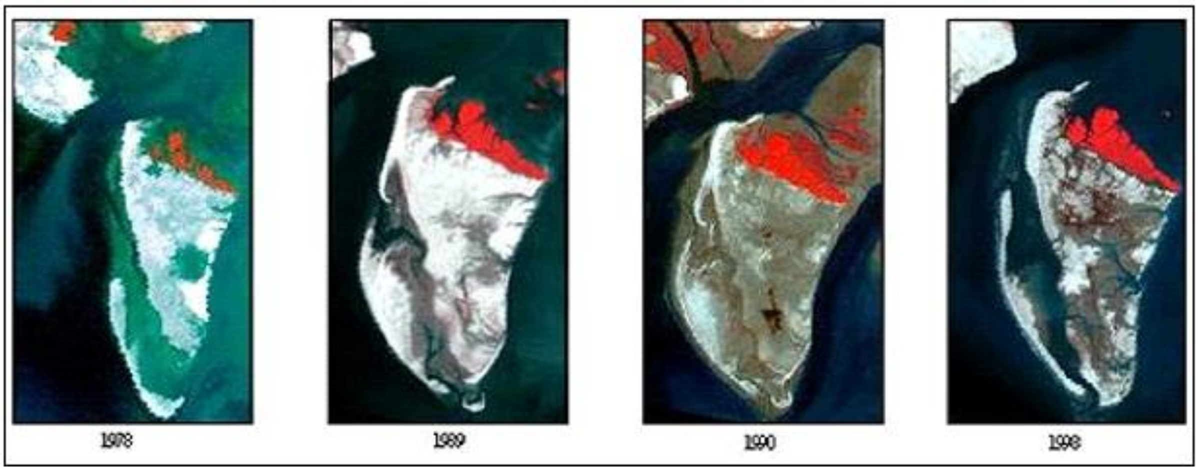

Fig. 7. Comparison of morphological changes occurred since 1978 to 1998 (NIO, 2001).

The ratio of minimum to maximum peak flows was increased to 1:5.9 during the post-Kotri period, which was more than double of the pre-Kotri period.

The overall impacts of man-made changes in the Indus River system are best observed downstream Kotri Barrage where prior to the Kotri barrage there were no days without water discharge (Fig. 3).

Fig. 8. Mining of beach sand in front of a residential complex at Clifton Beach, Karachi.

In the pre-Kotri period (1956-61), there was not a single day with a zero flow during both the *winter* and *summer* seasons. Zero flow days were observed during the post-Kotri period (1962-67).

The occurrence of zero flow days progressively increased following the commissioning of the Kotri and Guddu barrages and the Mangla dam in the winter season.

In fact, the frequency of zero flow days in the winter season has a direct impact on the downstream system. In the post-Kotri period (1961-67), the maximum number of days with zero flows in the *winter* season was 10. This increased to 180 days in the post-Kotri and post-Mangla period (1967-75).

The present situation is much more alarming due to below average rain fall in the Indus River catchment area as there are only two months (August-September) in a year when Indus flows downstream Kotri Barrage.

The construction of the barrages and the link and irrigation canals has, over the years, led to a systematic abstraction of water from the Indus. The coastal and marine scientists, being fully aware of consequences of decline in fresh water discharge, raised their concerns. According to some early estimates, construction of barrages, dams, and link canals has reduced the freshwater flow downstream from 180 billion m^3/year to less than 43 billion m^3/year (IUCN, 1991).

Fig. 9. Dredging of sand from low water line.

It was also predicted that further development programmes would further reduce the outflow into the sea by 12 billion m^3/year (Meynell and Qureshi, 1993). Unfortunately the actual effect of the man made diversions in the Indus River is much more alarming and the future of the delta is almost certain to be bleak as evident by some latest data (Fig. 4).

According to the irrigation sources, on July 13, 2002 the upstream flow at Tarbela was 171,000 cusecs and downstream 180,000 cusecs; at Chashma upstream flow was 213,000 cusecs while downstream was 200,000 cusecs; at Taunsa Barrage upstream flow was 194,000 and downstream was 166,000 cusecs; at Guddu Barrage upstream flow was 167,329 cusecs and downstream was 129,381 cusecs; at Sukkur Barrage the water flow upstream was 121,526 cusecs while downstream it was 60,911 cusecs; at Kotri Barrage the upstream flow was 367,000 cusecs and downstream was zero cusecs
(The News, July 14, 2002).

Under the APN funded project for sediment, carbon and nutrient flux studies, NIO scientists regularly monitored the Indus River downstream Kotri Barrage. Zero discharge was observed during most part of the year between Sajawal (which is equidistant ~90km from upstream Kotri Barrage and downstream river mouth at Khobar creek.

The fresh water reached the deltaic area infrequently during the summer (July-September). Recently Irrigation officials, Government of Sindh expressed his apprehension over the discharge of only 0.7 MAF of water downstream Kotri Barrage (Daily Jung, November 5, 2002).

Fig. 10. Inundation of Marine Drive, Clifton Beach Karachi is now a regular feature during South west monsoon.

Fig. 11. Destruction and incision of Marine Drive, Clifton Beach Karachi due to high wave action.

As a consequence, the river south of Kotri shows increased braiding and sand bar development (Fig. 5). Sediment passing down the system tends to be deposited in the section below Kotri, rather than maintaining the growth of the delta. This has increased the risks of high flooding, and clear channels to the delta must be maintained through releases of flushes of water.

Within the flood plain below Kotri barrage, the flood *bunds* extending from the barrage have significantly reduced the area flooded at peak flows and the distribution of flood waters through the different channels and creeks into the delta. The active delta is now only 119,169 ha compared to the 618,000 ha before these works were completed (Asianics Agro-Dev. International (Pvt) Ltd., 2000).

Fig. 12. One of the drainage canals in the Indus deltaic area of Keti Bunder where the sea water is entering into the irrigation land through the faulty gate. (Muzaffar *et al,* 2017).

The Indus River, that was responsible for the creation of one of the largest delta and submarine fan system in the world due to the large volume of sediments, is currently contributing hardly any sediment now. Consequently, there has been intrusion of sea water upstream of the delta - at places extending up to 75 kms in the coastal areas of Thatta, Hyderabad and Badin districts. Sindh's Irrigation and Power Department (IPD) has revealed that seawater intrusion has resulted in tidal infringement over 1.2 million acres of land in the Indus Delta. The twin menace of almost total absence of fresh water in the river downstream of Kotri 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 - causing desertification and displacement of several hundred thousand local residents who had been living there for many generations. 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.

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.

Coastal developments

Karachi, the largest city of Pakistan, is situated along the coastline in close proximity of Indus Delta.

Being an industrial and commercial hub, Karachi is expanding rapidly. The largest industrial estate of Karachi is situated close to the coastline. During 1970's the construction work of Port Bin Qasim was started to facilitate the industrial sector and also to provide relieve to the Karachi Port. A 45Km long navigational channel in the Phitti Creek connects Port Bin Qasim with the open Arabian Sea. The deepening and widening of that channel has apparently initiated severe coastal erosion problem in the area and so far resulted in the massive destruction of barrier islands which used to act as the nature's first line of defense against coastal erosion (Fig. 6).

Although the coastal changes on island and offshore areas were noted since charting time in 1846, the accelerating hydrodynamic changes have occurred probably due to deepening and widening of the approach channels of Port Bin Qasim in the 1970's resulting in destabilisation of sediments (Fig. 7). Indications are that erosional forces continue to alter the hydraulic regime in the area even though the remedial measures to stabilize coastal sediment erosion through plantation of mangrove have been taken. Prior to developmental activities in this area all costal processes were naturally controlled.

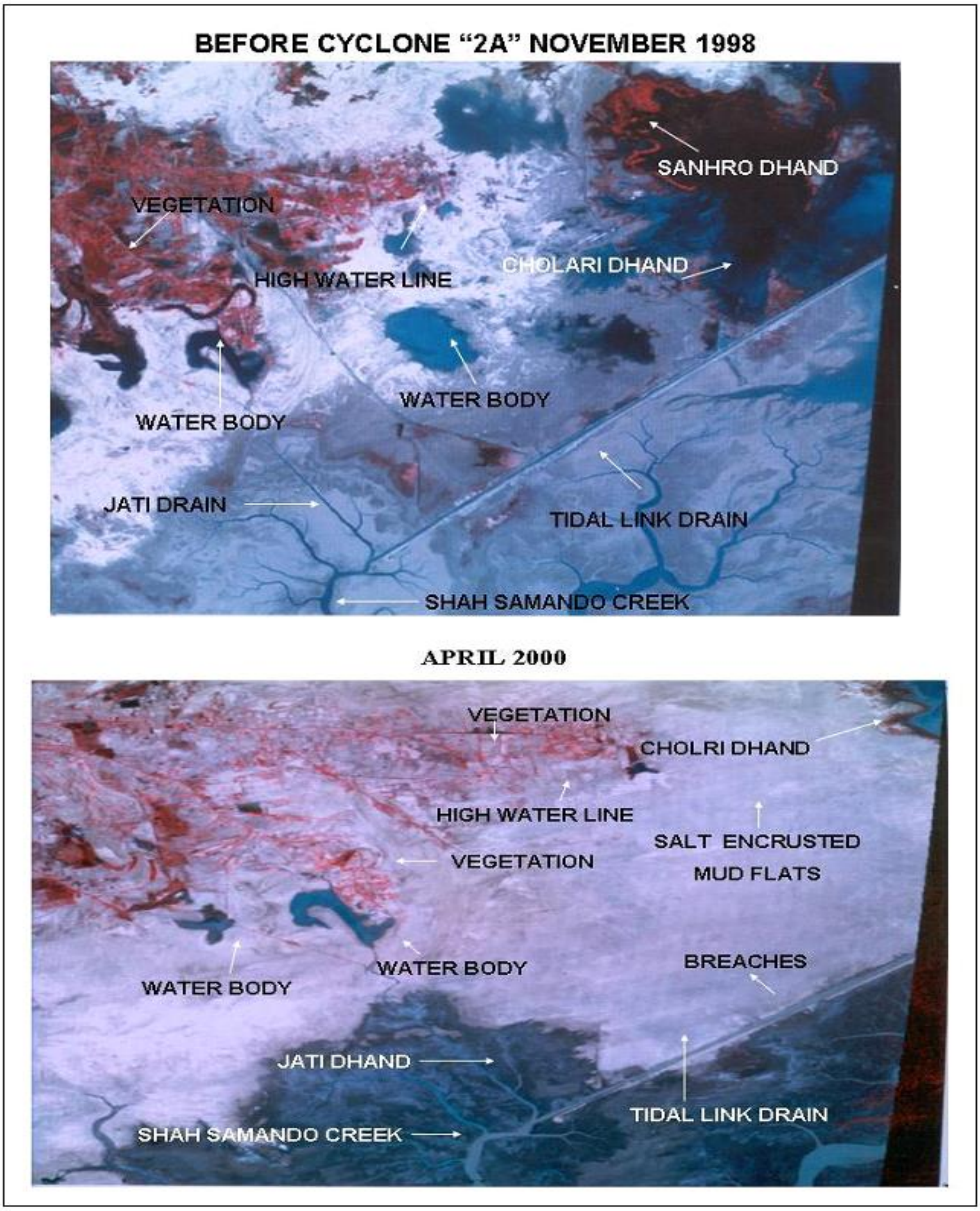

Fig. 13. Devastation of Cyclone 2A in south eastern area of the Indus Delta (NIO, 2002).

Un-planned dredging and beach sand mining

The posh residential area of Karachi is located on the coastline. Additional coastal areas are being reclaimed for new residential schemes. However, these reclamations are being carried out without giving due consideration to the implications of reclamations on the coastal dynamics. For immediate economic benefits, the developers are using sand excavated from the adjacent beach as infill material without realizing that beach sand provides protection from high energy waves (Fig. 8).

In the recent past, reclamation of an area that received water during spring tides. Here, the material was dredged from depths as shallow as 5m, against the normal practice of dredging in more than 20m water depth (Fig. 9).

This reclamation has changed the pattern of energy dissipation on the beach face of Clifton resulting in the inundation of road during spring tides in south west monsoon periods (Fig. 10). The situation has further deteriorated due to coastal erosion and resulted in the development of water inlet and total destruction of Marine drive along the portion of the Clifton Beach (Fig. 11).

Agriculture Runoff, Water Logging and Salinity

The topography of Sindh is more or less flat, the natural flow of drainage is gradual that results in rapid increase in ground water table. The prevalent canal irrigation system has resulted in large scale water logging and salinity problems. To mitigate the menace of rising ground water and associated problem of water logging and salinity, a network of drainage canals was constructed down in 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 it has in fact resulted in the sea water intrusion up to about 80Km upstream (Panhwar, 1999). The sea water intrusion is much worse during the southwest monsoon (Fig. 12).

The Cyclone "2A" that landed in the Southern coast of Indus Delta during 20-21 May 1999 and caused huge losses to life and property, coastal settlements, development infra-structure, crop lands, agriculture industry in Thatta and Badin Districts. Vast low lying areas in south adjoining Jati and Badin were inundated by the sea water. The four large dhands (Cholri, Sanhro, Mehro and Pateji) in the area merged into one large dhand. A number of coastal settlements, agriculture crops and fish farms were washed away by the cyclone. The communication net work including telephone lines, roads, well sites and the Tidal Link Drain, LBOD were extensively damaged. The sea water intruded into the irrigation land through the Tidal Link Drain of LBOD and resulted in the total calamity (Fig. 13). Extensive damage was caused to the drainage system that has now collapsed and is not functional anymore.

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). 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. 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).

Conclusion

Climatic change in the regional level causes socioeconomically damages which will be increase in the near future due to the anthropogenic impact in Indus deltaic region. Banks along the major and minor creek are shifting due to the massive tidal inundation.

Keti Bandar and shahbander cities facing socio-economical losses due to the sea water intrusion especially coastal erosion. Continuous increment in amount of fresh water and sediment to be discharged in to the Indus delta on year round basis.

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