



## An assessment of nutrient, sediment and carbon fluxes to the Indus Delta

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### Abstract

Nutrient and carbon flux play a significant role in the deltaic nourishment. These fluxes significantly involved in the stability of deltaic coast. Recent studies reflect that Indus River discharge is subtracted due to Khobar Creek, which is presently the only creek that carries the fresh water of Indus River into the Arabian Sea. There has been a drastic reduction in the load of nutrients brought by Indus River for the last fifty years. This reduction in Indus discharge has a negative impact on the Indus estuary and the productivity of the mangrove forest and fisheries. The Indus River bed sediments have relatively low values of calcium carbonate (< 10%) because sand contains relatively high concentrations of mica (36%), quartz (37%) and feldspar (11%) with very little percentage of detrital carbonate sediments. The organic carbon and calcium carbonate content in the sediment samples obtained from the area averages <1% and <15% respectively. Low values of the  $C_{org}$  (< 1%) were obtained for the bed samples of the Indus River. The bed sediments are generally composed of fine sand size material. Therefore, they have comparatively less  $C_{org}$ . The Indus River water and sediment discharge to the deltaic area and eventually to Arabian Sea is limited to few days during the months of July and August.

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## Introduction

The Indus River has a total length of more than 3,000 km (wwf.panda.org) and a drainage area of some 950,000 km<sup>2</sup>. Almost 90% of the water in the upper portion of the river basin comes from glaciers located in the Himalaya and Karakoram mountain ranges, which border China, Pakistan and India, and the Hindu Kush, which borders Pakistan and Afghanistan.

The Indus Delta is a typical fan-shaped delta, built up by the discharge of large quantities of silt washed down from upland and mountain areas. The present Delta covers an area of about 600,000 hectares and is characterised by 17 major creeks and innumerable minor creeks, mud flats and fringing mangroves (Meynell and Qureshi, 1993). The mangrove ecosystem of the Indus Delta is perhaps unique in being the largest area of arid climate mangroves in the world. As annual rainfall is so low in the region, mangroves are almost wholly dependent upon freshwater discharges from the river, supplemented by a small quantity of run-off and effluents from Karachi. The total available freshwater flow in the Indus is about 180 billion m<sup>3</sup>, carrying with it some 400 million tons of silt (Meynell and Qureshi, 1993). Over the last 60 years a series of dams, barrages and irrigation schemes have been built in upstream parts of the River Indus. 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. Pakistan's vast irrigation feeds more than 15 million hectares of farmland, with the highest irrigated to rain-fed land ratio in the world. This irrigation system is exerting a heavy toll on the environment. In particular there is concern that the abstraction of large volumes of water from rivers has, in many cases, left insufficient flow to meet the needs of downstream ecosystems.

As a result of upstream water abstraction mainly for irrigation by the time the Indus reaches the Kotri Barrage, there is inadequate flow to maintain the natural ecosystems of the Indus Delta. It is estimated

that up to 0.5 million hectares of fertile land in Thatta and adjoining areas (IRIN, 2001) or about 12% of total cultivated area in the entire Province (Government of Pakistan, 2001), is now affected by sea water intrusion. In addition to crop losses, this has resulted in severe damage to livestock through rangeland depletion, shortage of fodder, pasture and watering areas resulting in mass migration of both livestock and human populations out of the area.

The status of the Delta's natural ecosystems has already become critical, and the rural economy of the region faces an emergency situation as a result. The phenomenon of sea intrusion into the Indus River Delta has become one of the most politically-charged environmental issues in Pakistan today. Competition over water allocation within river basins, especially between upstream and downstream areas, between large-scale and subsistence-level uses, and between commercial and ecosystem uses, is becoming a source of severe economic and political conflict. In many ways the Indus Delta case study epitomises a national situation which has already reached crisis point, and is likely to deteriorate still further in the future (Memon, 2005). For now, national policies have opted to allocate scarce water so as to maximize financial and commercial returns to agriculture - often at the cost of natural ecosystems, and of some of the country's poorest communities. Yet there is growing concern that the failure to factor ecological economic values, or economic losses, into river basin planning is resulting in decisions being made about water allocation that are neither ecologically nor economically optimum. As long as the economic value of ecosystem needs for freshwater flows is marginalized in national decision-making, these conflicts are likely to escalate.

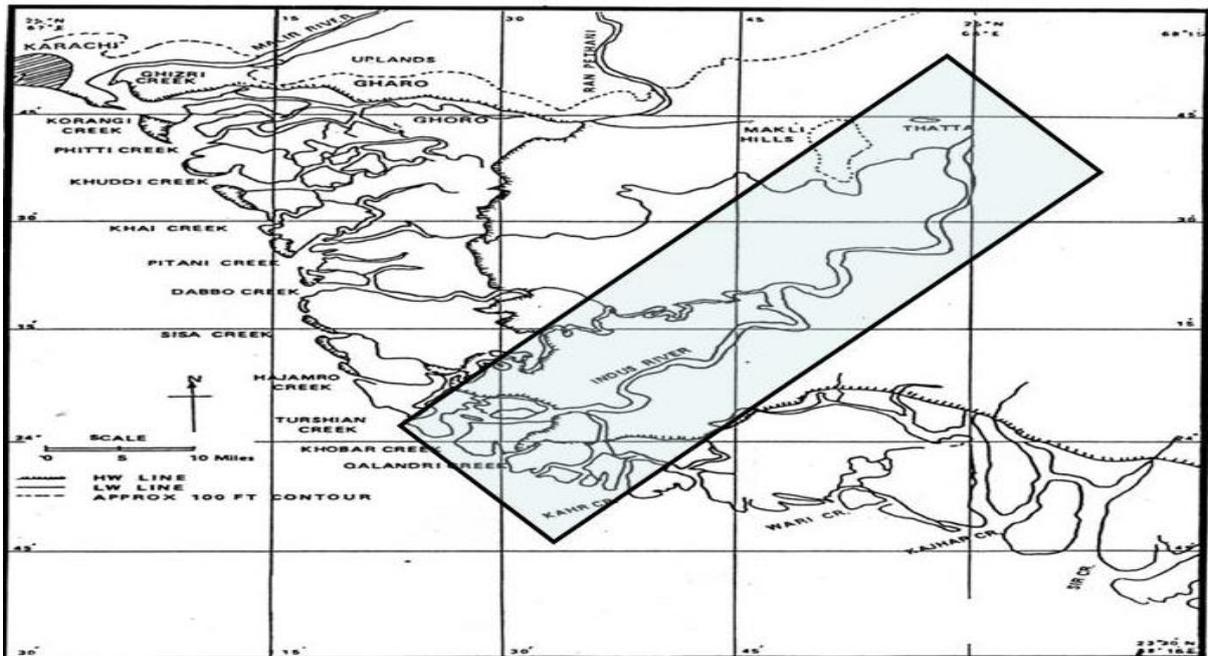
## Methods and laboratory analysis

### *Sampling strategy*

The study area under the project was primarily Khobar Creek, which is presently the only creek that carries the fresh water of Indus River into the Arabian Sea (Fig. 1 & 2).



**Fig. 1.** Satellite image of the Indus Delta. Inset shows the sampling stations on the Khobar Creek.



**Fig. 2.** Map of the major creeks of the Indus Delta. The shaded portion indicates the sampling site on the Khobar Creek.

An intensive study, comprising of current metering, echo-sounding, water and sediment sampling was undertaken downstream Kotri Barrage to Khobar Creek to quantify sediment and biogeochemical budgets.

However, to ascertain the baseline values of nutrients an endeavor was made to collect sediment and water samples from all the major barrages and dams on the Indus River.

*Gap filling studies*

*Collection of data and samples*

Current Metering: Aanderaa RCM 7 was used for recording of current speed and direction, water temperature conductivity. Current metering was carried out at the confluence of tributaries in the Khobar Creek. Observations were obtained and recorded for continuous 25 hours (during spring tide).

Water samples at one hour interval were also collected during the 25 hour continuous current meter observations.

Echo-sounding: Furuno echo-sounder (Model FE - 4300) was used for the bathymetric profiling of Khobar Creek.

**Table 1.** Salinity and nutrient concentration in the Khobar Creek for two seasons.

Seasons	Sources	Salinity (psu)	DIP (μM)	DIN (μM)
Dry	River runoff	0	0.11	0.24
	Inner	20	0.13	0.27
	Ocean	36	0.70	0.44
Wet	River runoff	0	0.12	0.21
	Inner	0	0.3	0.35
	Ocean	33	0.4	0.46

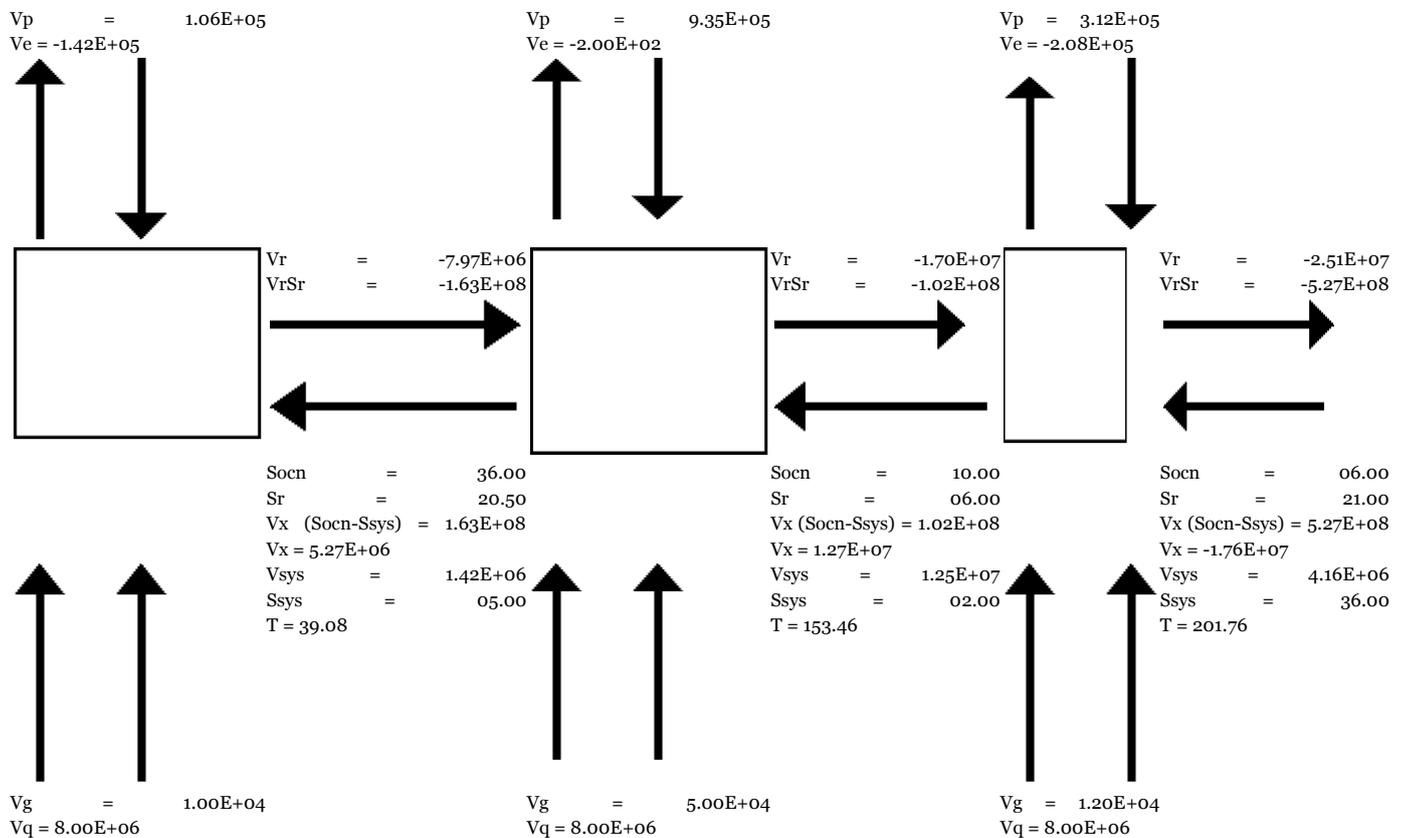
Navigation and Positioning: Garmin 12 XL GPS was used for navigation and determining the coordinates of the sampling stations.

sampler was used for sediment sampling. 1.2L Niskin bottle was used for water sampling. The criterion for spacing between stations was to follow a salinity gradient.

Sediment and water sampling: Van veen type of grab

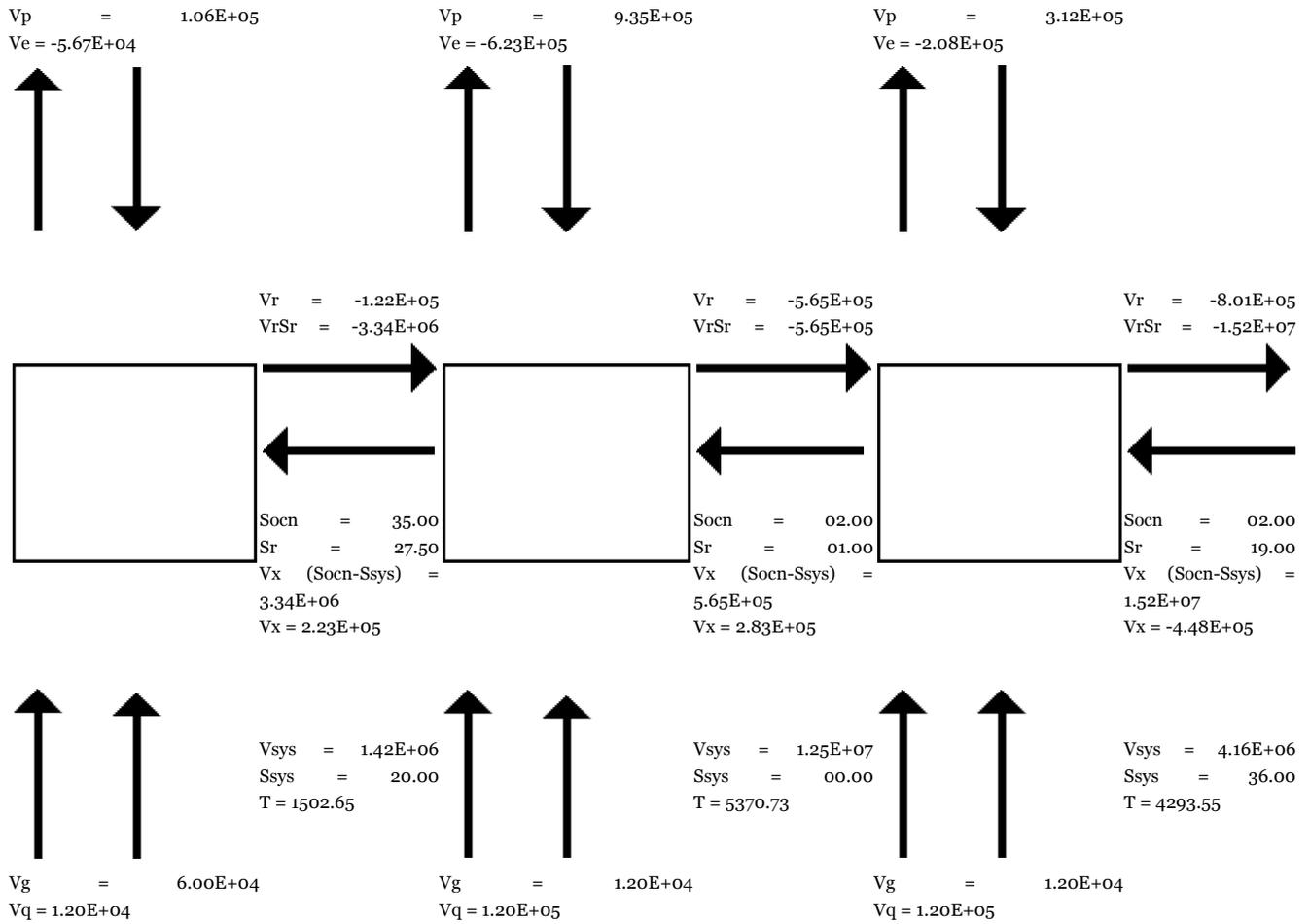
**Season 1 Water and Salt Balances**

Volume in m3 Water Fluxes in m3/yr Salt Fluxes in psu.m3/yr Time in days



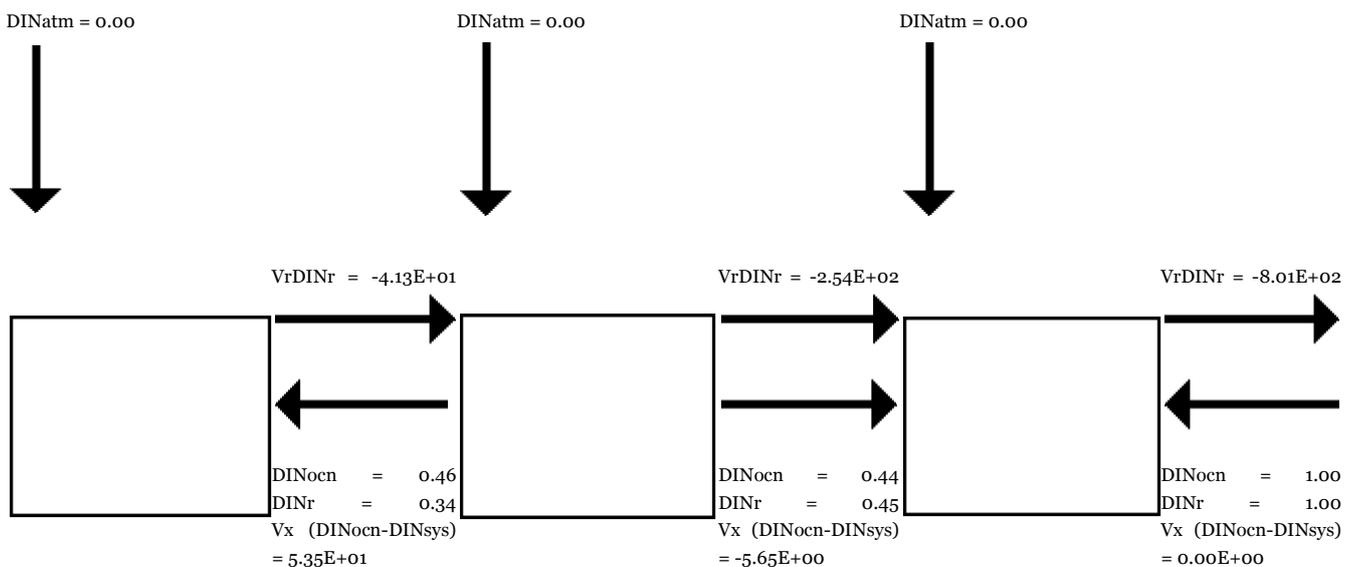
**Season 2 Water and Salt Balances**

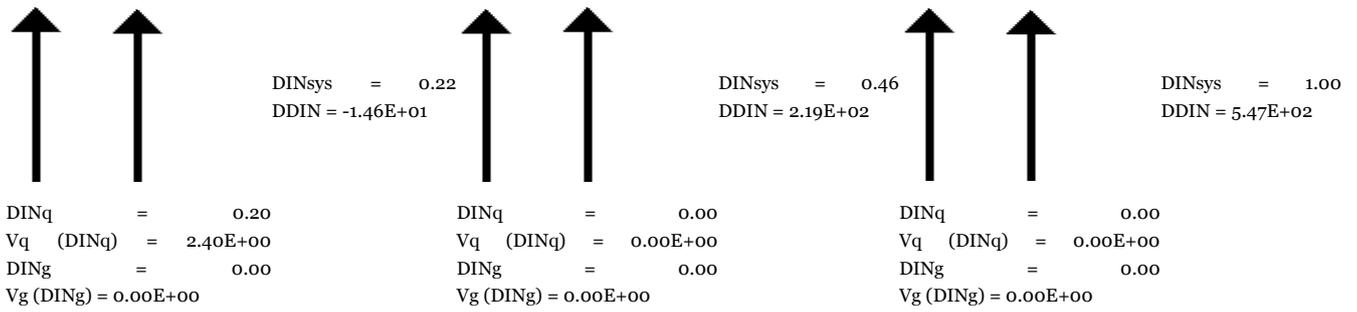
Volume in m3 Water Fluxes in m3/yr Salt Fluxes in psu.m3/yr Time in days



**Season 2 Nitrogen Balance**

Concentration in mmol/m3 Fluxes in mol/yr





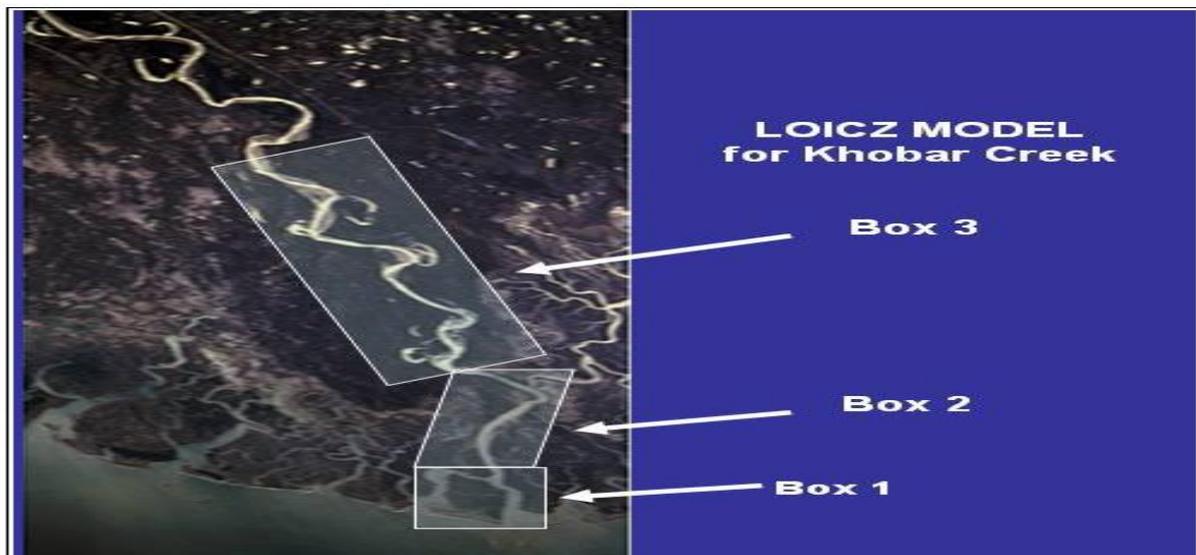
*Laboratory analyses*

Sediment samples were analyzed on Micromeritics Sedigraph 5100 and LECO's CR-412 Carbon Determinator for grain size and carbon content. Nutrients in water samples collected from various locations from Indus River were analyzed according to standard international protocols.

*Synthesis of fluxes and nutrient budgets*

The tidal, estuarine part of the Indus River at Khobar Creek covers a length of about 40 km and a basin area of 36 km<sup>2</sup> (Kalhoro *et al.*, 2016). On the basis of

physical characteristics it can be classified as partially-mixed coastal plain estuary. Hydrographical and hydro-chemical characteristics of the river exhibit seasonal variability. The water temperature reaches a maximum of 30°C during the southwest (summer) monsoon and a minimum of 15°C during the winter. Budgets for the estuary are therefore calculated for two seasons: wet season (July-August) and dry season (November-December). Based on the salinity variations the estuarine system has been divided into three boxes (Fig. 3, Table 1).



**Fig. 3.** Location of Boxes for the nutrient budget calculations.

*Nutrients*

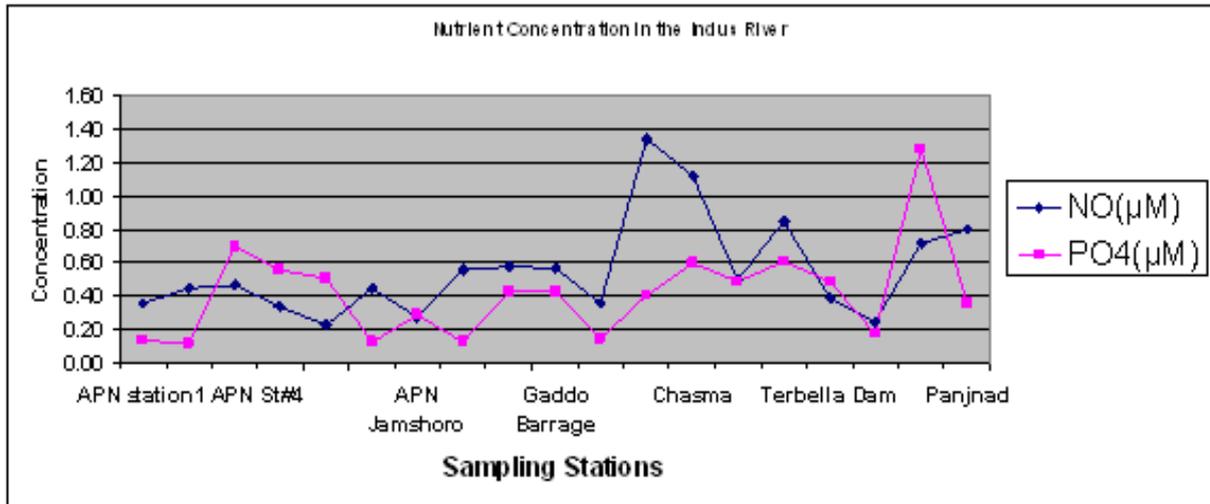
There has been a drastic reduction in the load of nutrients brought by Indus River for the last fifty years. This reduction in Indus discharge has a negative impact on the Indus estuary and the productivity of the mangrove forest and fisheries.

Major nutrients (nitrite, ammonia, phosphate and silicate) were measured all along the Indus River water over a distance of about 1000 km from Terbel Dam to Khobar Creek through which the river water discharges into the Arabian Sea. Since the silicates were very high, in order to document the trend of Nitrite and phosphate in the transect, the distribution of other nutrients are omitted from the figure (Fig. 4).

**Bathymetry**

The echo sounding of the river bed in the Khobar Creek area revealed very steep variations, especially at the confluences of tributaries in the major creek, where the river bed is much deeper (>15m) and rugged (Figure 5).

The bottom topography indicates erosive phases that are characteristics of rivers with large sediment and water discharge. However the bathymetric data obtained during the present study is not sufficient to assist in the assessment of hydrodynamics of the Indus River in the Khobar Creek.

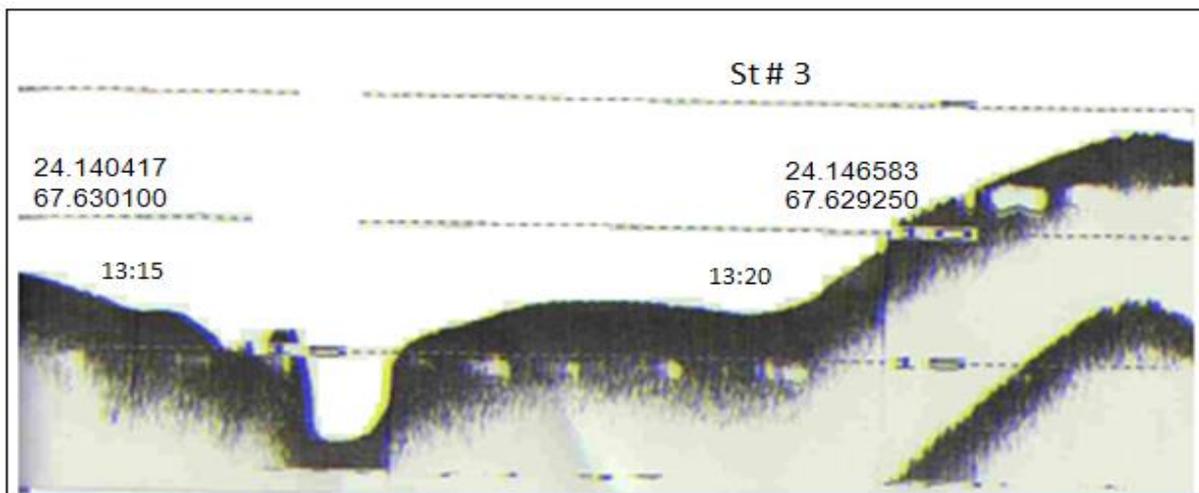


**Fig. 4.** Nutrient concentration in the Indus River.

**River bed sediments**

The sediment samples collected from the area are, in general, relatively compact fine grained and mostly range between fine sand and clay size fraction (Fig. 6).

Sand percentage was generally low except at river mouth and at Jangisir where it was probably deposited during high flood periods. The coarseness and compactness of bottom sediments is also depicted as strong bottom echoes.



**Fig. 5.** Echo profile of the Sajan wari (the site of 25hrs current meter observations) depicting rugged bottom topography indicative of erosional features at the confluence of tributaries.

In general, the mean grain size value suggests that the river flow is not strong enough to carry coarse sediments downstream to the river mouth. Whatever sediment the Indus River has carried to the delta limits itself within the Khobar Creek till the event of flood that flushes out the unconsolidated sediment to the Arabian Sea.

The mineral composition of the sediments obtained from the Khobar Creek confirms that the sediment is Indus River derived. No marine components were found, evident by the absence of any shell fragments of marine origin. The coarse sediments at the river/creek mouth are reworked by wave and tidal processes, while the gentle slope helps sediment deposition.

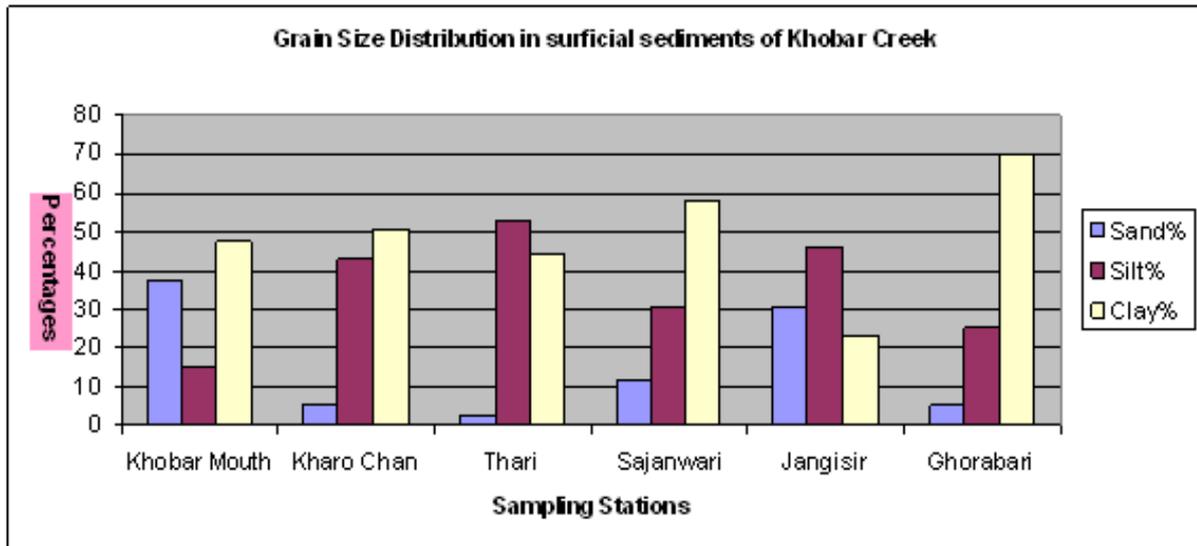


Fig. 6. Grain size distribution in surficial sediments of Khobar Creek.

*Current velocity and direction*

The analysis of 25 hours current velocity and direction data recorded in the Khobar Creek during the spring tide in July 2003 indicates that the maximum velocity was 154 cm/sec at flood and ebb stages while minimum

velocity was 10 cm/sec (Figure 7). The volume of water discharged through the system can be calculated if the average velocity of water flow, average water depth and the width of the channel are known.

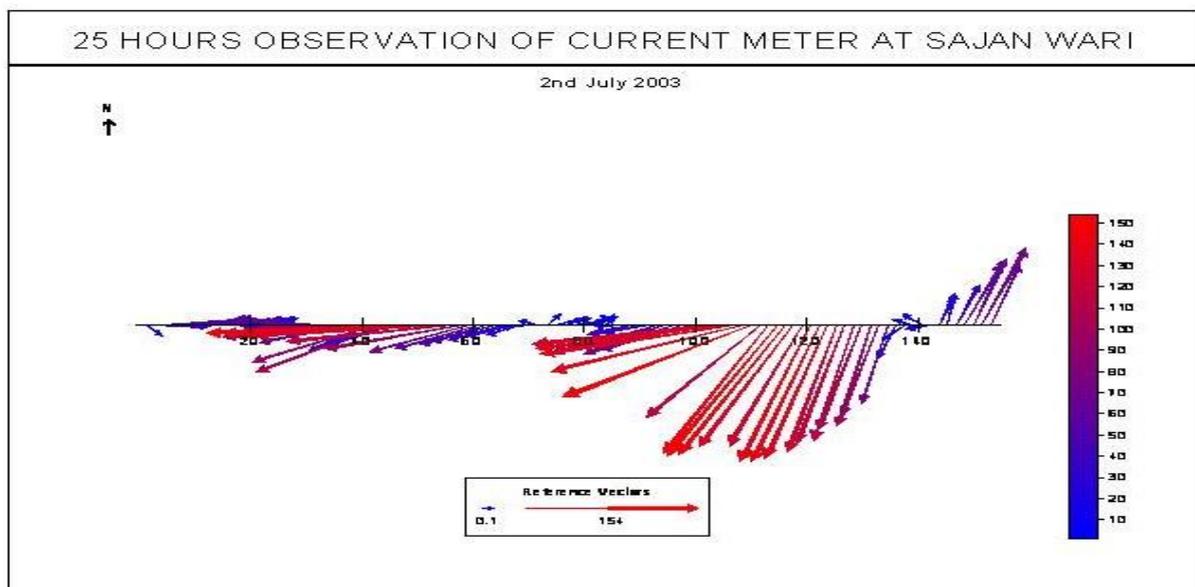
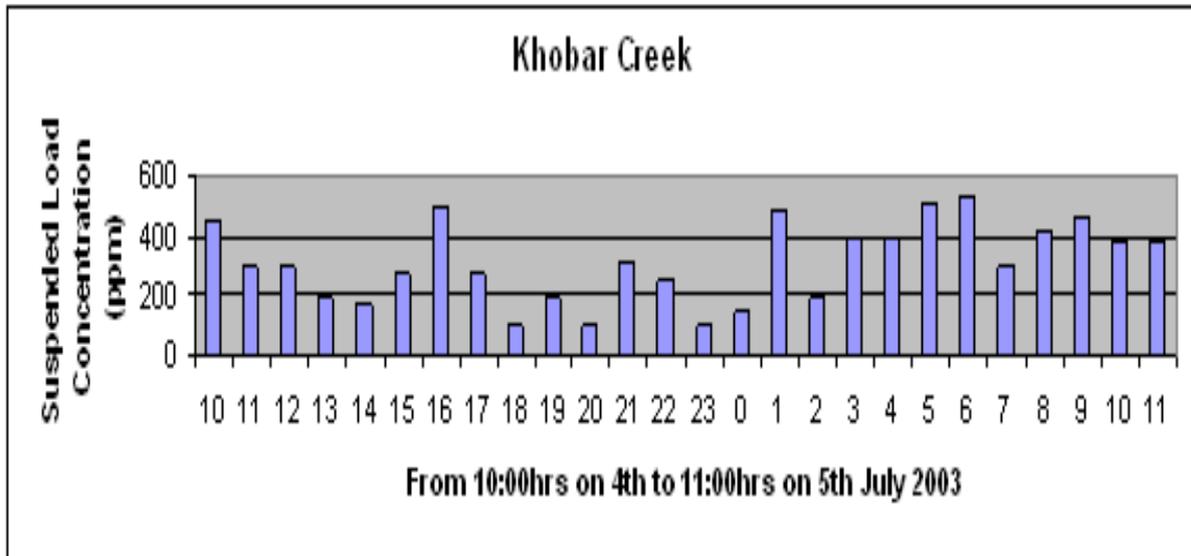


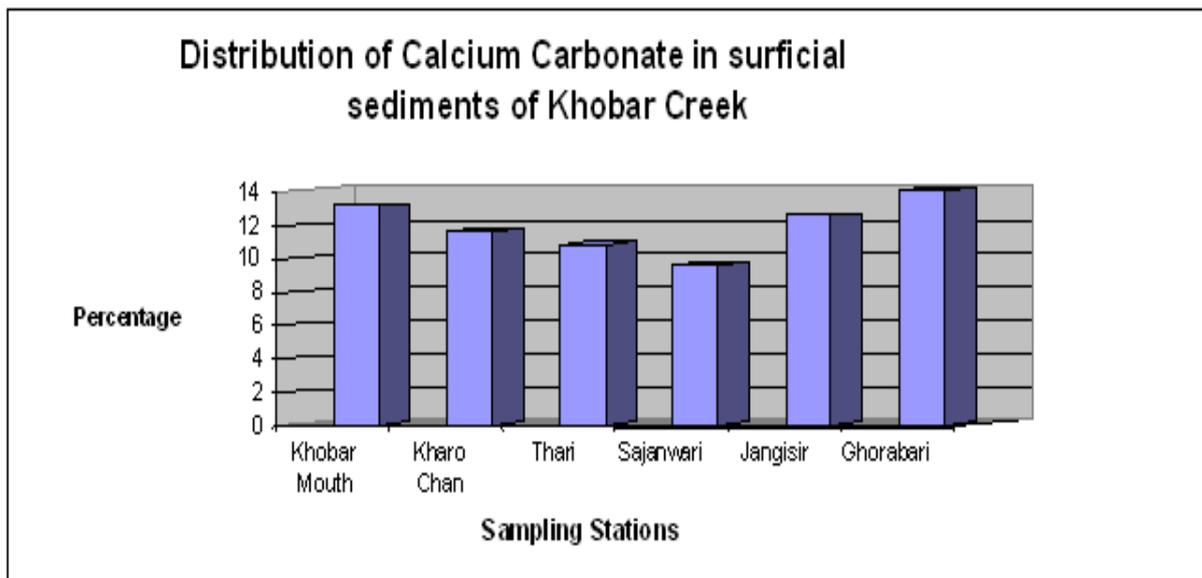
Fig. 7. 25 hours current meter observations at Sajanjwari, Khobar Creek.

The average depth of the Khobar Creek is ~17m; width (at the mooring site) is 1100m. Therefore the volume of water discharged through the Khobar Creek (at the time of observation) during the ebb and flood tide

ranged approximately between 1870m<sup>3</sup>/sec and 28840m<sup>3</sup>/sec respectively. While the average volume of water flowing at the time of observation was 13500m<sup>3</sup>/sec.



**Fig. 8.** Suspended sediment concentration plotted with reference to salinity variations during 25 hours continuous observations in Khobar Creek.



**Fig. 9.** Distribution of Calcium carbonate in the surficial sediment of the Khobar Creek.

*Suspended sediment concentration*

The suspended sediment concentrations measured at different locations on the Indus River showed substantial variation. The concentration of suspended sediment is directly linked with the water discharge in the river.

The suspended load monitored at Kotri (about 200 km from the river mouth) ranged between 65 and 92 ppm. Torrential rain in July 2003 in the lower Indus Basin contributed towards relatively high suspended load concentrations in the section downstream Kotri Barrage (4569 ppm) to river mouth at Khobar (3948 ppm).

Since the 25 hrs observations were carried out in the first week of July i.e., just prior to the onset of heavy rains, the data presented in Figure 8 does not show high sediment concentrations.

The suspended load measured during the 25 hour continuous observation in Khobar Creek is plotted in Figure 8. Though there was substantial variation in

the salinity with the diurnal variation in tide, no apparent change was observed in the suspended sediment concentration (Fig. 8). This probably because the movement of relatively strong ebb and flood tide keeps the fine sediments in suspension and retards their deposition. The grain size data obtained from the Khobar Creek further substantiate this hypothesis.

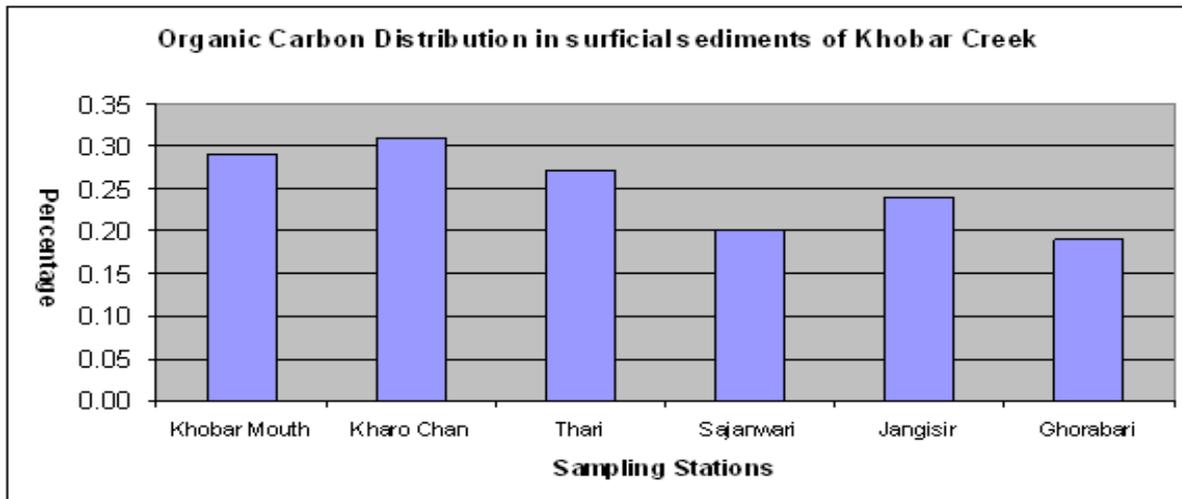


Fig. 10. Organic carbon distribution in surficial sediments of Khobar Creek.

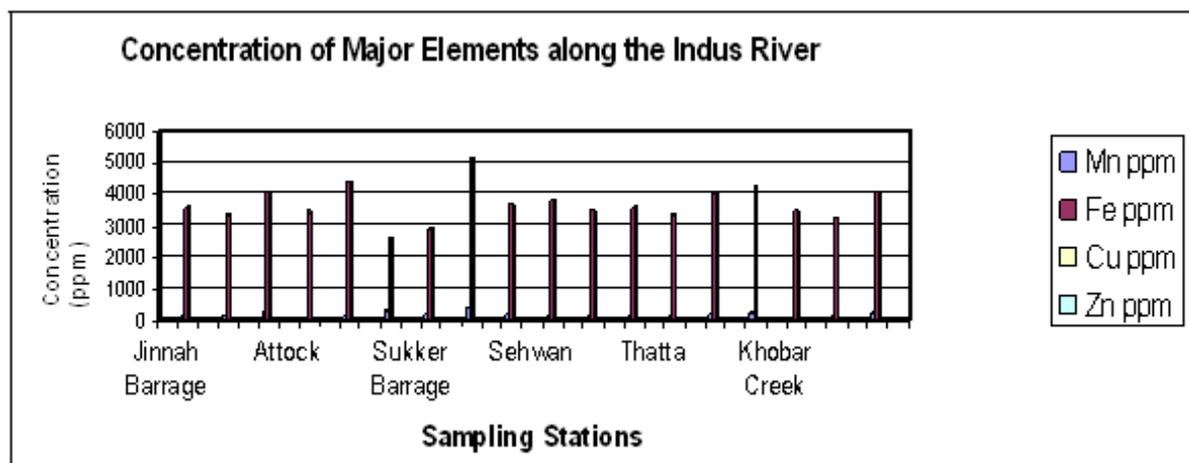


Fig. 11. Distribution of major elements along the Indus River.

*Turbidity*

In Khobar Creek the light penetration was up to a depth of <1.0 m. Turbidities are 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 were high after the raining season of southwest monsoon.

*Organic carbon and calcium carbonate*

The Indus River bed sediments have relatively low values of calcium carbonate (< 10%) because sand contains relatively high concentrations of mica (36%), quartz (37%) and feldspar (11%) with very little percentage of detrital carbonate sediments.

The organic carbon and calcium carbonate content in the sediment samples obtained from the area averages <1% and <15% respectively (Fig. 9 & 10).

Low values of the  $C_{org}$  (< 1%) were obtained for the bed samples of the Indus River. The bed sediments are generally composed of fine sand size material. Therefore, they have comparatively less  $C_{org}$ .

#### *Mineralogical and elemental analyses*

Generally, quartz, albite and muscovite are the common minerals with the exception of clinocllore, anorthite sodian in the coarser river sediments. Illite, chlorite and montmorillonite are the common clay minerals. Concentration of heavy metals in the river sand and fine-grained deltaic sediments have relatively high values of iron (Fe) that ranges between 2600 and 5000ppm, while Mn ranges from 47.43-370.90 ppm, Cu ranges from 5-26.32 ppm, Zn ranges from 14.51-46.38 ppm, Cr ranges from 10.7-30.70 ppm, Ni ranges from 11.26-123.56 ppm and Pb ranges from 4.2-13.52 (Fig. 11).

#### **Conclusion**

The Indus River water and sediment discharge to the deltaic area and eventually to Arabian Sea is limited to few days during the months of July and August. Extensive sediment coring is proposed in the deltaic area and in the lower part of the Indus River. A hydraulic station should be established so that water and sediment input into the system can be quantified. The total sediment thickness and volume of the Holocene delta should be quantified through 3.5kHz seismic surveys. On the subaerial delta a sediment facies map should be made in order to define the sedimentary sub-environments and their formative processes. It seems likely that measurements in localities strongly affected by the SW monsoon will have to be restricted to the winter months. The most dynamic period will then be missing in the data, but experience has shown that a substitute for this may be sought in the sedimentary record (box- and other undisturbed cores). In the tidal channels, and in the sub aqueous delta quantitative data should be obtained through echo sounding, by monitoring wave and tidal height, current velocity, current direction,

and suspended as well as bed load. From the structures in the cores the relative importance of sediment depositing and transporting processes should be evaluated. Long term study of Indus River and delta is suggested to document the negative impacts of water and sediments starvation on the ecology and socio-economy of the area.

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