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INCREASED SEA WATER INTRUSION IN THE VICINITY OF TIDAL LINK DRAIN AT SOUTH SINDH (PAKISTAN)

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ABSTRACT: The Tidal Link Drain is a man made drain which delivers the drainage water across Pateji and Cholri Dhands into the Arabian Sea via Shah Samando creek. The Tidal Link is 41 Km long from its point of juncture with Kaddan Pateji Outfall Drain (KPOD) in the North-East up to Shah Samando Creek in the South-West. The vertical tidal range in the area is about 5 m. The tidal link was designed to carry about 3,118 cusecs of drainage waters. After completion of Tidal Link Drain, sea water intrusion and high erosion/sedimentation have been noticed at the tidal link and adjacent area due to changes in the hydraulic regime in the area. The devastation caused by tropical cyclone "2A" in May, 1999 in the Indus delta has also created some drastic morphological changes in the area. This physical process creates breaches in the Tidal link drain between RD-30 and RD-125. These openings allow free exchange of water between the tidal link drain, Dhands and the Rann of Kutch.

The analysis of tidal behavior, tidal current measurements and water samples collected in the study area shows that a small tidal creek type system of drainage channels has now been developed in Cholri Dhand and this system of channels is now used to flush water during ebb tide from surrounding Dhands of LBOD through Tidal Link Drain. It is observed that the LBOD can now be described as a "New River" that is forming an "Estuary", which is an integral part of the creek system of the coastal area. The tidal link now acts as a tidal stream in which tidal fluctuations are very much visible and the sea water is now approaching the land. The main problem concerning the LBOD outfall is the increased hydraulic gradient due to seawater intrusion. The LBOD run parallel to the Indus River and discharges the saline water at the same level (sea level) in an active creek area of the Shah Samando Creek. The same altered hydraulic gradient creates very strong ebb currents in the region, which are responsible for making breaches in the tidal link drain and erosion and accretion in the Dhands.

KEYWORDS: Tidal Link Drain, LBOD, Dhands (ponds), saltwater intrusion, Indus delta, hydraulic gradient, 1999 cyclone, sea level rise.

INTRODUCTION

Irrigation in the Sindh Province of Pakistan has a history of several thousand years. A major program of improvement and construction of new inundation canals was undertaken in the latter half of the 9th century. In 1932 the barrage commanded irrigation was introduced with the construction of the Sukkur Barrage system commanding a gross area of some eight million acres on the left and right banks of the River Indus. Later, two other barrages, Kotri (1955) and Gudu (1962) were constructed to complete the system as it is today (WAPDA, 1997).

Virtually all commands of Sukkur Barrage are supplied with perennial water and this supports a summer (Kharif) crop which is mainly cotton, and a winter (Rabi) crop which is largely wheat. It was known in 1932 that the command would eventually require drainage, but with the deep water tables prevailing at that time, it was not initially needed. Some 50 to 60 years ago the water table in the project area was a minimum of 12 feet below ground level (World Bank, 1997). By 1981, the water table was less than 5 feet over 75 percent of the Project area. Since the annual rainfall in Sindh is low, irrigation water has primarily been responsible for the rise in water table and build-up salts in the soils. Since there is no natural route for ground water to drain, an estimated one ton of salt was added to every irrigated acre in Sindh every year (WAPDA, 1997). Over the last decade, many farmers in the project area were unable to cultivate because their farmlands have become saline.

The Left Bank Outfall Drain was first proposed for the Lower Indus in 1966. The project was conceived to control water logging on 1.27 million acres of land in the districts of Nawabshah, Sanghar and Mirpurkhas through a network of open-surface drains that conveyed the saline effluent pumped by tube wells via a spinal drain and a tidal link into the Arabian Sea (World Bank, 1998). The Tidal Link Drain and surrounding region are shown in Figure-1.

That study broadly proposed that the drain should be aligned from the Rann of Kutch and taken north through the command area. Before 1932 lower Indus areas had water tables below 12 feet, 50 years later 75 percent of these areas had water tables less than 5 feet and 20 percent less than 8 feet, (WAPDA, 1997). Due to rising water tables and the associated increase in salinity of the non-cropped areas, land is decreasing and abandoned land increasing. The result is that farmers are forced to intensify cropping on their best land. Similarly, Bengston *et al.* (1996) have described the agriculture drainage and water quality in the Mississippi Delta and reported that the subsurface drainage was effective in reducing surface runoff by an average of 35% and soil loss by 31%. In order to solve the problem of water logging and salinity WAPDA constructed an artificial dredged drain known as Left Bank Outfall Drain (LBOD) and Tidal Link Drain, which is connected to the Shah Samnado Creek of Indus delta (Delft Hydraulics, 1988). This artificial drain which starts from Kaddan Pateji Outfall Drain (KPOD) and finishes at the Shah Samando Creek is 41 Km long (Hall, 1997). On 21st May, 1999 cyclone “2A” hit the coastal areas of Thatta and Badin. Due to the cyclone, the Tidal Link Drain was damaged seriously and breaches occurred at 56 locations (Fisher folk Forum, 2004; NIO, 2002) which resulted in sea water intrusion in the Tidal Link Drain (Al-Agha, 2004). It has also been found that all four Dhands, Cholri, Pateji , Mehro and Sanhro, have been under the influence of seawater due to breaches in the Tidal Link Drain (NIO, 2002; NIO, 2004).

According to the World Bank Report (2005), southwest monsoon depressions in 1998 destroyed a portion of the Cholri Weir and the cyclone “2A” in 1999 destroyed the entire weir and damaged the Tidal Link Canal. While the Tidal Link continues to function despite the numerous breaches in its embankments to convey drainage water to the sea under normal conditions, the destruction of the Cholri weir has led to apparent changes in salinity and water balance of the Cholri and Pateji Dhands, which in turn has had a negative impact on the biodiversity and productivity of these Dhands. It is quite evident that the Cholri, Pateji, Mehro and Sanhro Dhands have become more saline (NIO,

2004) and the increase in salinity have negative impacts on the agriculture, fisheries, habitat of migratory birds as well as socio-economy of the communities of the Tidal link Drain and Dhands areas.

In order to sustain and improve the ecosystem and socioeconomic condition, it is of prime importance to study the impact of seawater intrusion in the area. The present study deals with the extent of saltwater intrusion in the Tidal Link Drain and the surrounding region. The impact of sea encroachment due to probable sea level rise and hydraulic gradient has also been discussed.

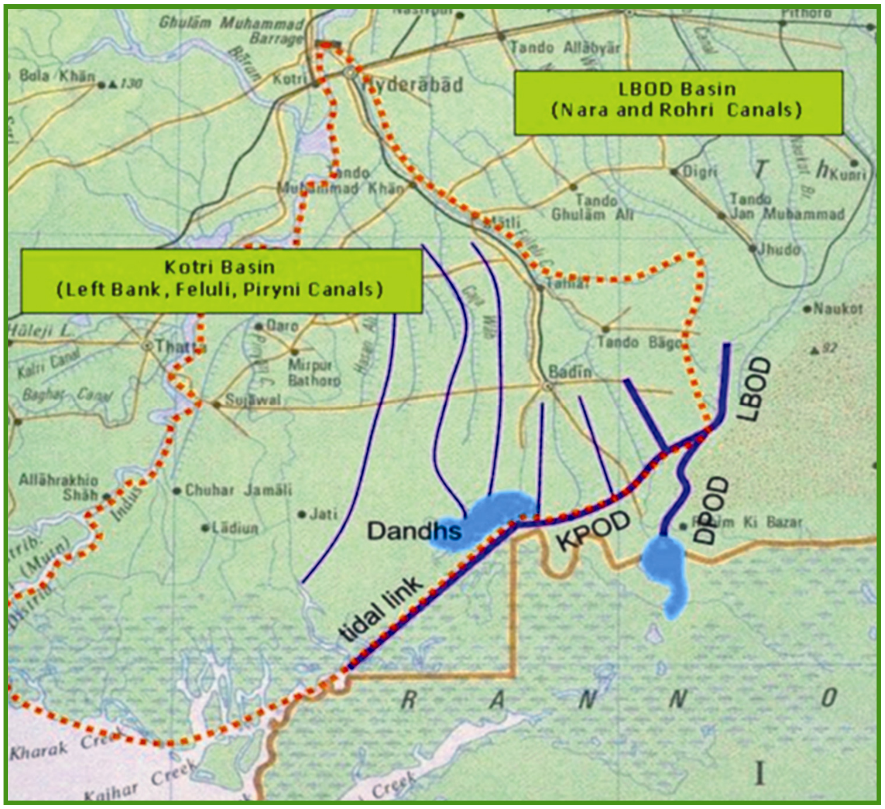

Fig. 1. Map shows LBOD and surroung region, located in the Southeastern coast of Sindh in Badin District (Source: panel of Experts Drainage Master Plan, 2004).

STUDY AREA

The Tidal Link was designed to carry about 3,118 Cusecs of drainage waters (NDP, 2004). The tidal link alignment passes across Pateji and Cholri Dhands which are interconnected with Mehro and Sanhro Dhands filled with brackish/saline water and support a diverse ecosystem, fisheries and sanctuary of migratory birds. The excess water from these Dhands has historically drained into the Rann of Kutch which is now blocked by the Tidal Link. The tidal Link is divided into fraction named RD (1 RD = 0.265 Km).

The Tidal Link Drain starts from RD0 and the last point is in the Shah Samado creek which is RD-155. The total distance of Tidal Link Drain between RD0 to RD-155 is about 41 Km (WAPDA, 1996). The study area with RDs along the Tidal Link Drain and surrounding Dhands are shown in Figure-2.

MATERIALS AND METHODS

The tidal observations, current measurements and water sample collections were made at the selected sites of the 41 km long Tidal Link Drain. In this study, a base station was established at the site of RD0 (Serani Dhyand) of the tidal link drain for the continuous monitoring of water salinity, tidal behavior, hydrographic and meteorological parameters of the drain. The current and water level measurements were taken at different RDs. The current meter (COMPACT-EM, Japan) was moored at different locations for monitoring of water current behavior with the passage of time. Mostly 25 hrs observations were taken to cover the semidiurnal tidal cycles of the study area. The Tide gauge (TR-1050, Canada) was used to record water levels at RD0 and RD-93. The meteorological parameters were observed by using an automatic weather station (Watch Dog 900ET, USA). The AWS was installed on the top of research laboratory at RD0. The water samples for salinity and suspended load analysis were collected during the field observations at different RDs in the Tidal Link Drain and from the Dhands areas. The Bathy-500MF single beam Echo-sounder was used for the collection of Bathymetric data (NIO, 2006). State of the art techniques and protocols were applied for a position-fixing Navigation during the field observations by using GPS. The water sampling and data monitoring stations in the study area are shown in Figure-2.

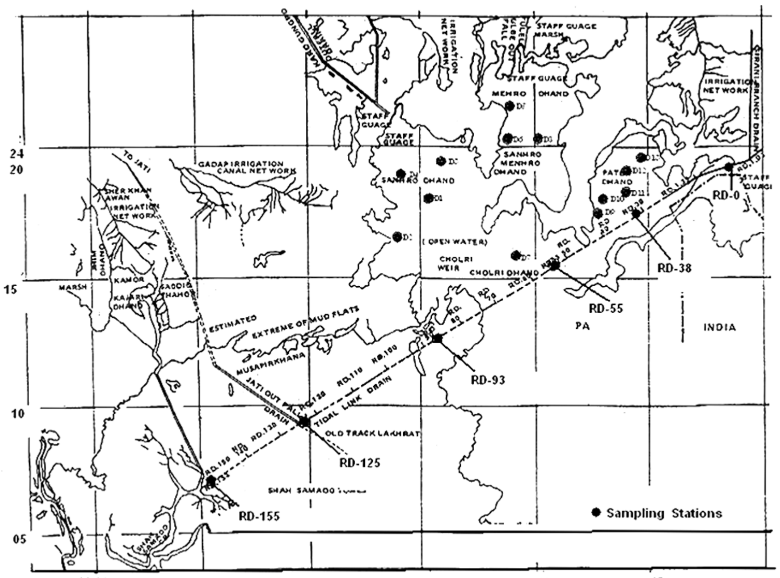

Fig. 2. Sampling stations within the Tidal Link Drain and surrounding Dhands (Source: National Institue of Oceanography, Pkaistan).

RESULTS AND DISCUSSION

Tidal fluctuations:

The tidal data observed at RD-93 and RD0 during 1999-2008 was processed and analyzed. The yearly tidal variations at RD-93 and RD-0 are shown in Figure-3 and Figure-4 respectively. The RD-93 is about 17 km from the mouth of the tidal link drain (Figure-2). The analysis of collected tidal data provides some significant changes in the tidal behavior at the lower part of the Tidal Link Drain. The analysis of tidal data shows that there is an increase in tidal range with the passage of time. The comparison of observations taken before and after the catastrophe of 1999 cyclone "2A" at RD-93 shows that there is an increase in tidal range from 0.3 m to 0.4m (NIO, 1998).

Though RD0 is about 41 km from the mouth of the tidal link drain, the analysis of water level data observed at RD0 from 1999 to 2008 indicates that the natural tidal behavior is now observed at RD0. This shows that the sea water is now reaching at RD0. The time series of HHW (Highest High Water) and (Lowest Low Water) observed at RD0 depicts that the tidal range has been increased from 0.4 m to 0.8 m during 1999 to 2008 (Figure-4). This could possibly be due to the increased erosion and sedimentation in the tidal link drain and the creation of more than dozen breaches in the tidal link drain between RD-30 and RD-125. These breaches (openings) allow free exchange of water and a marked increase in seawater influence in the drain, which is likely to hinder the smooth drainage of agriculture saline water from LBOD to Arabian Sea. It is also noted that the Tidal Link Drain played an important role in the water exchanges among Dhands and the Tidal Link Drain.

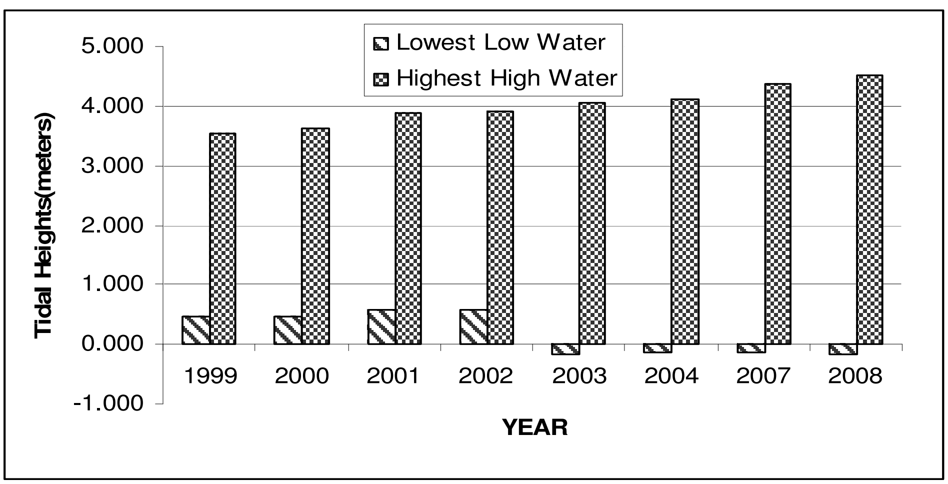

Fig. 3. Yearly average High High water (HHW) and Low Low water (LLW) heights (m) at station RD-93.

Water Currents:

The sea water current measurements were taken at different stations during SW and NE monsoon seasons. The yearly bar chart of tidal currents observed during the SW monsoon and the NE monsoon at RD-93 at the time of ebbing and flooding are shown in Figure-5 and Figure-6 respectively.

The observations of the water current at RD-93 confirm the expected increase in the influence of sea water with stronger Ebb and Flood currents. The Ebb-current velocities vary seasonally from 145 cm/sec to 190 m/sec from NE monsoon to SW monsoon respectively. Similarly, the current velocity in flooding varies from 90 cm/sec to 110 cm/sec during the NE monsoon and the SW monsoon respectively. The current observations show that the Ebb currents are quite strong and this situation is likely to increase erosion tendencies in the tidal link and adjacent areas particularly during the period of strong summer monsoon. The downward flow of drain water in the tidal link drain is supported by Ebb tides (NIO, 1998). The ebb tidal current pattern during northeast monsoon depicts that during the dry season the discharge of saline water towards the sea through tidal link drain have relatively lower velocities as contribution of rain water is almost zero during the NE monsoon season.

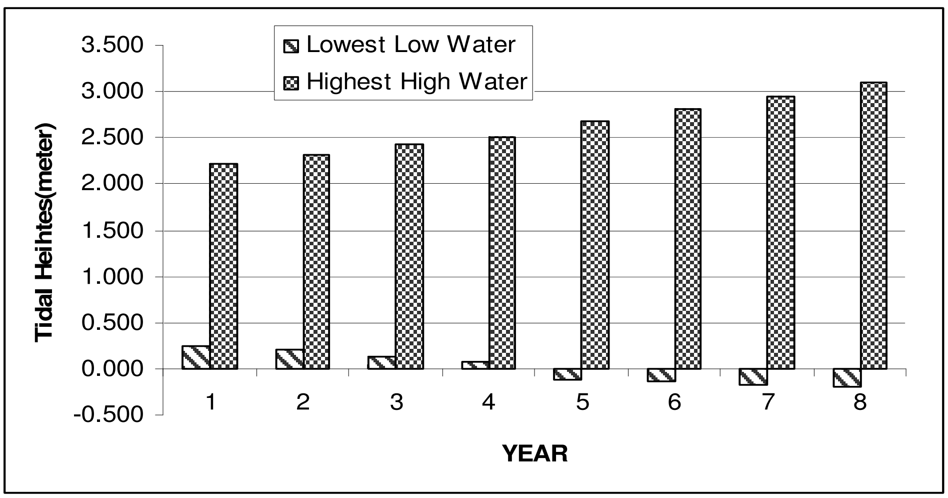

Fig. 4. Yearly average High High water (HHW) and Low Low water (LLW) heights (m) at station RD0.

The yearly variations in tidal currents both in ebbing and flooding indicate that the average current speed in the tidal link drain is continuously increasing and the Ebb current velocities are much stronger than the Flood. This could be attributed to the total washout of Cholri weir at RD-55 and disturbing the designed water flow pattern in the area (World Bank, 2005). The yearly bar charts of tidal current observed during SW and NE monsoons at RD0 at the time of ebbing and flooding are shown in Figure-7 and Figure-8 respectively. This indicates that the influence of sea water has now traced up to RD0 and further inside.

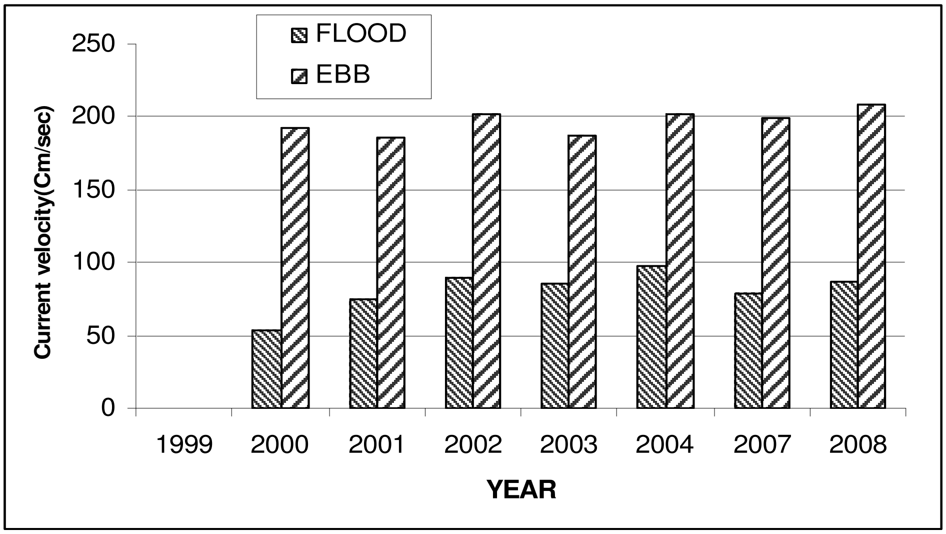

Fig. 5. Yearly variations of sea water current (cm/sec.) at RD-93 during SW monsoon.

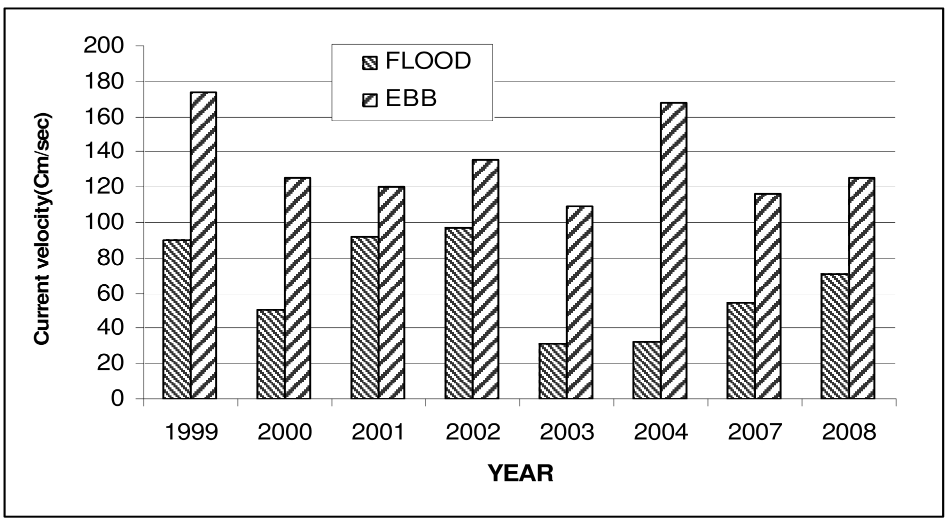

Fig. 6. Yearly variations of sea water current (cm/sec.) at RD-93 during NE monsoon.

The observations on the water currents at this site demonstrate the drastic increase in influence of sea water build up during stronger ebb and flood tides. This situation is linked, leading to breaches and new hydraulic regimes in the area, particularly during strong summer monsoon in the region. By the time it reaches at RD-38 it is already under hydraulic resistance for downward flow because of the two flood tides per day. On the other hand the two ebb tides per day accelerate the downward flow of drain waters in the Tidal link Drain. Therefore, the resultant flow of water is dependent on the speed of water currents during flood and ebb tides in the Tidal Link Drain. As the ebb tidal currents are stronger, therefore there is a net flow towards the sea.

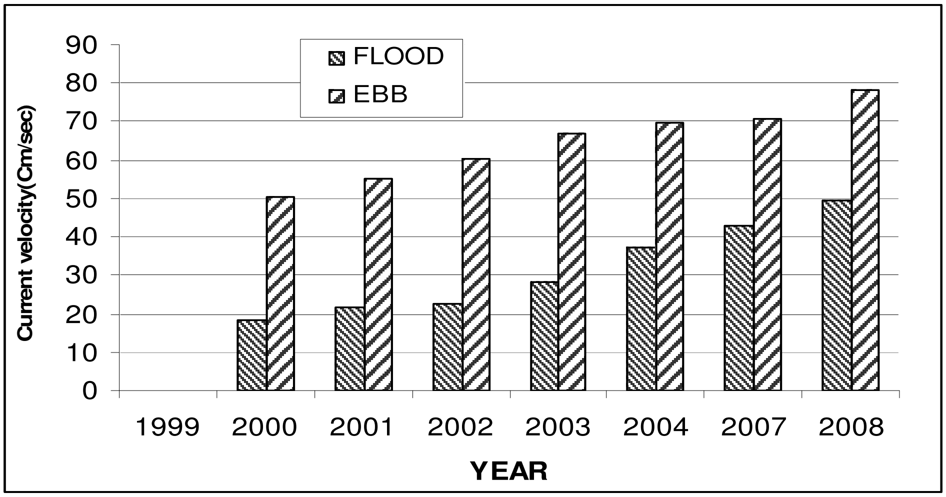

Fig. 7. Yearly variations of sea water current (cm/sec) at RD-0 during SW monsoon.

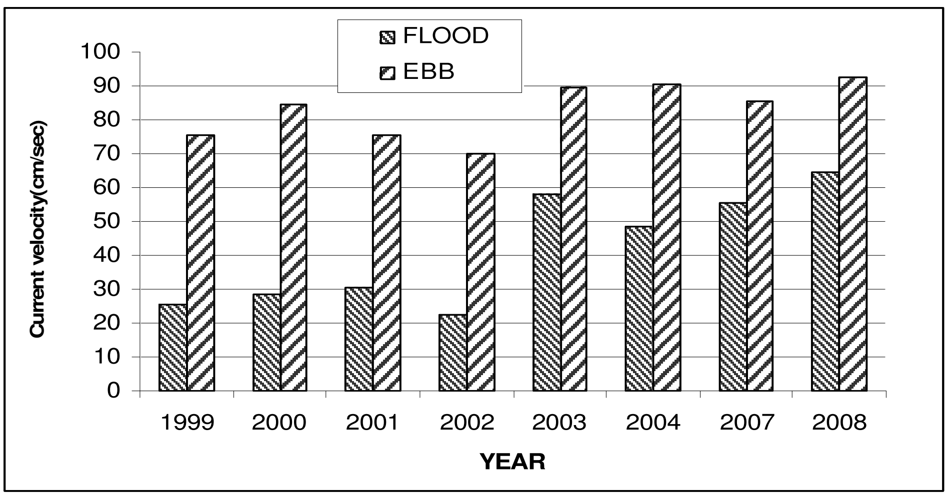

Fig. 8. Yearly variations of sea water current (cm/sec) at RD-0 during NE monsoon.

Water Discharges:

The observations of the average water current speed, corresponding Tidal levels and bathymetry were used to calculate the discharge of water from selected points at the Tidal Link Drain. The calculations also took into account the available information on the volume of the Tidal Link Drain. The changes in the volume of the Tidal Link Drain by erosion and accretion would alter these calculations considerably.

Due to the presence of several breaches in Tidal Link Drain has resulted in huge inflow and outflow of waters at RD-93 within the Tidal Drain. The net discharge of about

570 to 700 m^3/second was observed during August-September showing the over-all impact of the damage caused by the cyclone in the area. In contrast to this discharge situation there was a net discharge of about 177 m^3/sec at RD-93 during 1997 which is about 7 times less than the values of discharges observed at this point in 2008 (NIO,1998). This again is an indication that the hydraulic regime in the area has been changed considerably due to the several breaches created in the Tidal Link Drain, by the Cyclone "2A" in 1999. There is a clear indication that breaches in the embankments of the Tidal Link Drain due to Cyclone "2A" have restored the old gravity gradient and a complex hydraulic regime in the area. This has resulted increased hydraulic pressures in the Tidal Link Drain leading to hindrances in the discharges of the Agriculture Saline Drain waters from the LBOD / KPOD to the Tidal Link at RD-22.

Wind pattern and Hydraulic behavior of LBOD:

The predominant monsoon is the southwest monsoon that occurs between May and September. The southwest monsoon winds having an average speed of about 10 m/sec prevails in this area. The strong and persistent winds generate swell waves with a period of about 12 seconds, which strike the Badin coastline from southwest direction. The pilings up of water along the coast by strong wind are of extreme importance for flushing of Tidal link Drain water into the sea. However, during Ebb condition, the wave action and strong currents cause speedy flushing of salt water and increase the dispersion and dilution rate. Most of the time during summer monsoon season, SW winds with an average speed of 5 m/s prevail. However, during winter the light winds prevail in the region (NIO, 2006).

Sea Water Salinity:

The seawater salinity recorded at the tidal link drain is typical of estuaries for most part of the year. The yearly comparison of sea water salinity at different RDs shown in Figure-9 indicates little variation in the upper part of the tidal link drain as compared to the lower half of the tidal link drain. The average increase in the lower half of the tidal link drain ranges 8-12ppt.The water average salinity at RD-155 during the study period was found 42 ppt (NIO, 1998). The water salinity at this site appears to be similar during the 1993-1994 period (the pre-operational period of Tidal link Drain) to the water salinity observed during 1995, 1996 (post operational period of Tidal Link Drain) .The sea water salinity recorded at RD-155 is a typical example of shallow creeks with high evaporation and less precipitation. The high surface water salinity is observed during the summer months, particularly in May-June-July. The observed salinity is between 35 ppt to 46 ppt indicating excessive evaporation during hot weather. The sea water surface salinity at the Tidal Link Drain from RD-155 to RD-125 of the Tidal Link Drain during the study period range from 30 ppt to 47ppt.

As the Embankments of the Tidal Link Drain have been washed away at several places, this situation has allowed free exchange of water between Dhands and Tidal Link Drain and higher saline water of Rann of Kutch during flood tides. The changes in bathymetry in the Tidal Link Drain have further promoted the influence of sea water in the Tidal Link Drain. It is a clear indication of salinity increase in the last few years at RD0. The increase in sea water salinity at RD0 shows that the influence of sea water intrusion has reached up to RD0. The yearly average salinity variation at RD-155, RD-125, RD-55 and RD0 show that the salinity values are going back to its normal values of pre 2A cyclone condition (1999). The increasing trends only observed in the year 2000 to 2003. The decrease in salinity started after 2004. The increment in salinity values after 2006 in the Tidal link drain may be linked to the changes in the bathymetry of the Tidal Link Drain and sea level rise, which have further promoted the influence of seawater into the Tidal Link Drain.

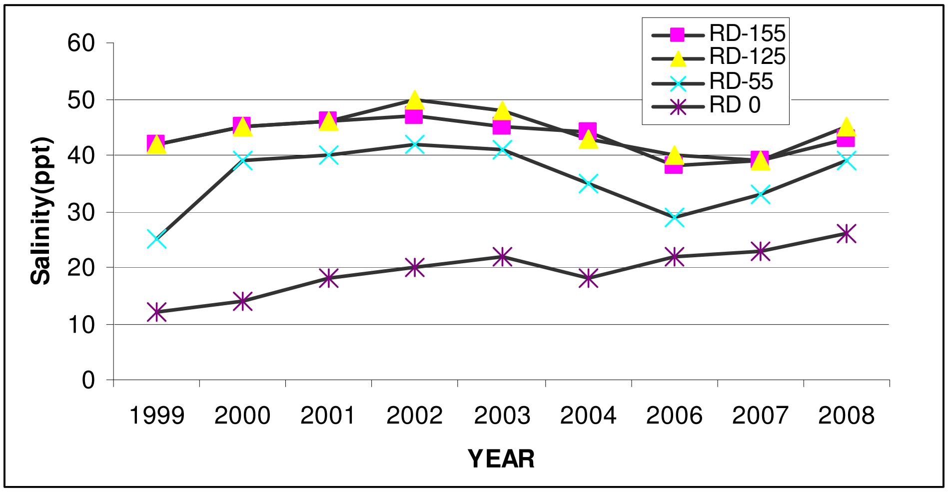

Fig. 9. Yearly variations in salinity (ppt)at different RDs of the Tidal Link Drain.

Impact of Sea water Intrusion into Dhands:

There are a few large brackish water shallow Dhands along the tidal link drain. There was free and frequent water discharge from Dhands to Runn of kutch prior to the construction of tidal link drain. Cholri dhand located adjacent to the tidal link drain is also interconnected with other Dhands in the area (e.g. Sanhro, Mehro and Pateji Dhands). Cholri dhand receives drain water from other Dhands and used to finally drain it to Runn of Kutch .This natural drainage passage from Dhands to Runn of Kutch has been blocked by the tidal link drain. There is a flow of water from the tidal link drain to cholri dhand is about 2-3 hours/day during spring high tide. The maximum water level in dhand areas has been reported to be 1.6 m during spring tide (McDonald and Partner, 1984).

As the tidal link drain was severely damaged by the cyclone in May 1999, more than a dozen breaches in the embankment of the tidal link drain have been formed. Due to these breaches in the embankment of tidal link drain between RD-38 to RD-93 (Middle of The Tidal Link Drain), there is now a free water exchange among the tidal link drain, adjacent Dhands and the Runn of Kutch. The unification of all major Dhands (brackish water) forms one large sea water body during high water condition, particularly during the SW monsoon period (May to August).

The depth of all four Dhands before cyclone “2A” 1999 was 0.5 m to 1.0 m (NIO,1998) and in the year 2003 the depth was found in between 0.3 to 0.7m (NIO, 2004). The area of some Dhands has been shrinking and depth is also reduced (SUPARCO, 2007). The observed yearly variations in depth of all four Dhands are given in Table-1. The observed bathymetric data show the continuous decline in depth ranges from 0.3 m to 0.6 m. Evaporation may also be considered an important part of the water balance of the Dhands.

The yearly salinity values of the surface water in the Dhands before and after the Cyclone 2A are presented in Table-1. The salinity variations with the passage of time show the continuous increment in the salinity of Dhands water after the cyclone 2A. This increment in salinity depicts the probable exchange of Dhands water with the sea water through the breaches in the Tidal Link Drain during flood tides. The exchange of sea water can brings chemical and bio-ecological changes at all four Dhands. These changes may also affect the food chain and associated fish fauna and birds.

The salinity increase was noticeable in Cholri, Sanhro Mehro and Sanharo Dhands just after the operation of the tidal link drain (NIO, 1998). Later on storms such as 1999 "Cyclone 2A" further worsened the situation. The storm, in July 2003, was the final blow and destroyed the already deteriorating Tidal Link Drain. The higher salinity values during 2003 depicts the combined effect of storm surge traces and higher evaporation rates in the Dhands water (SIDA, 2012). However, the heavy rain storms events with flash flooding in 2006 and 2008 in the Lower eastern Sindh, caused to decrease the salinity of the Dhands (SIDA, 2012).

The present study shows the tidal fluctuations much greater than estimated in the original design of the tidal link drain. Furthermore, the Tidal Link and its embankments altered the previous stream flow pattern in the tidal area of the Dhands. The breaches in the tidal link drain now concentrating the flow in some areas and facilitating new connections between the Dhands and the Tidal Link Drain. It appears that the erosion pattern shall continue upstream into the drainage system forming a wider and deeper channel and widening the connection to the sea. The LBOD can now be described as an estuary and the sea water approaches towards land through LBOD and now the tidal fluctuations are visible in the KPOD.

Table 1. Yearly salinity (ppt) variations with depth (m) of all four Dhands before and after the cyclone "2A"1999.

Year	Pategi Dhand		Cholri Dhand		Sanhro Mehro Dhand		Sanharo Dhand	
	Salinity (ppt)	Depth (m)	Salinit y (ppt)	Depth (m)	Salinit y (ppt)	Depth (m)	Salinit y (ppt)	Depth (m)
1997 (before cyclone 2A)	30.00	0.5	29.00	1.0	25.00	0.6	15.00	0.8
2001	30.00	0.60	32.00	0.80	30.00	0.60	35.00	0.70
2002	36.00	0.60	40.00	0.80	37.00	0.30	39.00	0.50
2003	37.00	0.60	41.00	0.70	41.00	0.30	47.00	0.40
2007	28.00	0.50	32.00	0.60	23.00	0.30	25.00	0.40
2008	29.00	0.55	37.00	0.62	26.00	0.32	20.00	0.41

The Badin District in the lower LBOD basin consists of extremely flat land that is susceptible to extensive inundation during heavy rain because of low infiltration rates and slow runoff (this condition prevails to a somewhat lesser degree in many areas of the upper basin as well). The natural drainage is also impeded in the monsoon season by the high tides and extensive flooding of the coastal zone, that is the natural outlet of this slow and shallow overland flow. It is therefore concluded on the basis of the available data, the hydraulic performance of the Tidal Link Drain has been reduced considerably and its effective length to carry Agriculture Saline Discharges to Shah Samando Creek have reduced up to RD–22 and RD-38 instead of RD–125 and RD-155 as per design.

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