MAUSAM, **69**, 4 (October 2018), 535-542

551.577 : 627.223.4 (549.19)

Impacts of tidal link drain, along the coastal areas of districts Badin and Sujawal in Indus deltaic region, Sindh Pakistan

NOORUDDIN KHASKHELI*, NOOR AHMED KALHORO*, #, $, JUN WANG#, ZHIGUO HE*, #, DONGFENG XU*, #, GHULAM RABANI TUNIO*, KAMRAN SHAHANI* and FAYYAZ SALIH HUSSAIN**

**Institute of Port, Coastal and Offshore Engineering, Ocean College, Zhejiang University, Zhoushan 315000, China*

#State Key Laboratory of Satellite Ocean Environment Dynamics, Second Institute of Oceanography, State Oceanic Administration, Hangzhou 310012, China

$National Institute of Oceanography, Karachi 75600, Pakistan

***National Center of Excellence in Analytical Chemistry University of Sindh*

(*Received 1 September 2017, Accepted 7 August 2018*)

e mail : noorahmed_niopk@yahoo.com

सार – सिंध पाकिस्तान के तटीय क्षेत्रों में समुद्री जल का आना और तटीय क्षरण के कारणों में से एक टाइडल लिंक नहर भी प्रमुख कारण है। सिंध के बदीन और सुजावाल जिलों के तटीय क्षेत्रों में समुद्री जल के अंदर आने के कारणों और प्रभावों की जाँच करने के लिए उपग्रह से प्राप्त हुए चित्रों तथा ज्वारीय आंकड़ों के साथ-साथ साहित्यिक समीक्षा का विश्लेषण किया गया है। इस अध्ययन में यह पाया गया है कि समुद्री जल टाइडल लिंक नहर के मुहाने से लगभग 70 कि.मी. अंदर तक और इस समुद्री जल के अंदर तक आ जाने से लगभग 2.95 मिलियन एकड़ कृषि-भूमि प्रभावित हुई है। इसी बीच पिछले 17 वर्षों के उपग्रह से प्राप्त हुए डेटा के आधार पर टाइडल लिंक नहर में प्रतिवर्ष 30 मीटर की दर से औसत क्षरण का अनुमान लगाया गया है। मगर समुद्री जल के अंदर आने और तटीय क्षरण से लेफ्ट बैंक आऊट फॉल ड्रेन साइट के पर्यावरणीय और सामाजिक जीवन पर दुष्प्रभाव पड़ रहा है। इसीलिए यहाँ की झीलों के पारिस्थितिक तंत्र को भी गंभीर खतरे का सामना करना पड़ रहा है। समुद्री जल के अंदर आने और तटीय क्षरण से मीठे पानी के झीलें तथा कृषि योग्य भूमि और भू-जल प्रभावित हुए हैं। दक्षिणी-पश्चिमी मानसून के दौरान दक्षिण में समीपवर्ती समुद्र का खारा पानी टाइडल लिंक ड्रेन (नहर) से होते हुए अंदर आकर बड़े भूभाग को जलप्लावित कर देता है। इस तटीय क्षेत्र की गतिशील प्रक्रिया को पूरी तरह समझने के लिए व्यापक रूप से इस क्षेत्र की जाँच और उच्च विभेदन वाले तटीय महासागर मॉडल की तत्काल आवश्यकता है जिससे आगे अध्ययन किया जा सके।

ABSTRACT. Tidal Link Canal has been one of the causes of seawater intrusion and coastal erosion along the coastal areas of Sindh Pakistan. The literature reviews, along with satellite images and tidal data were analyzed to investigate the causes and impacts of seawater intrusion along the coastal areas of Badin and Sujawal districts of Sindh. This study represents that seawater intrusion has taken place up to 70 km upstream from the mouth of Tidal Link Canal and about 2.95 million acres agricultural land has been affected by seawater intrusion. Meanwhile, on the basis of satellite data 30 m $year^{-1}$ average erosion rate was estimated for the past 17 years in tidal link canal. However sea water intrusion and coastal erosion are have a devastating environmental and social impact along the Left Bank Outfall Drain site, thus the whole ecosystem of lakes is facing serious threat. The fresh water lakes as well as agricultural lands and ground water have been affected by seawater intrusion and coastal erosion. During the southwest monsoon, the neighboring sea in the south inundates vast area with salt water through tidal link drain. Extensive field investigations and a high resolution coastal ocean model are urgently needed for future study to fully understand the dynamic process in this coastal region.

Key words – Tidal link canal, LBOD, Seawater intrusion, Coastal erosion, Future directions.

1. Introduction

The Indus irrigation system is one of the largest systems in the world where the irrigation water is spread over about 17.3 million hectares in Pakistan with number of tributaries, barrages, link canals and watercourses (Rizvi, 2001). Only the length of canals, watercourses and field ditches are about 60,800 km and 1.6 million km, respectively (Kahlown *et al*., 2002). About 5 billion m^3 of river water is being diverted to feed all the fore mentioned canals annually (Kahlown *et al*., 2002).

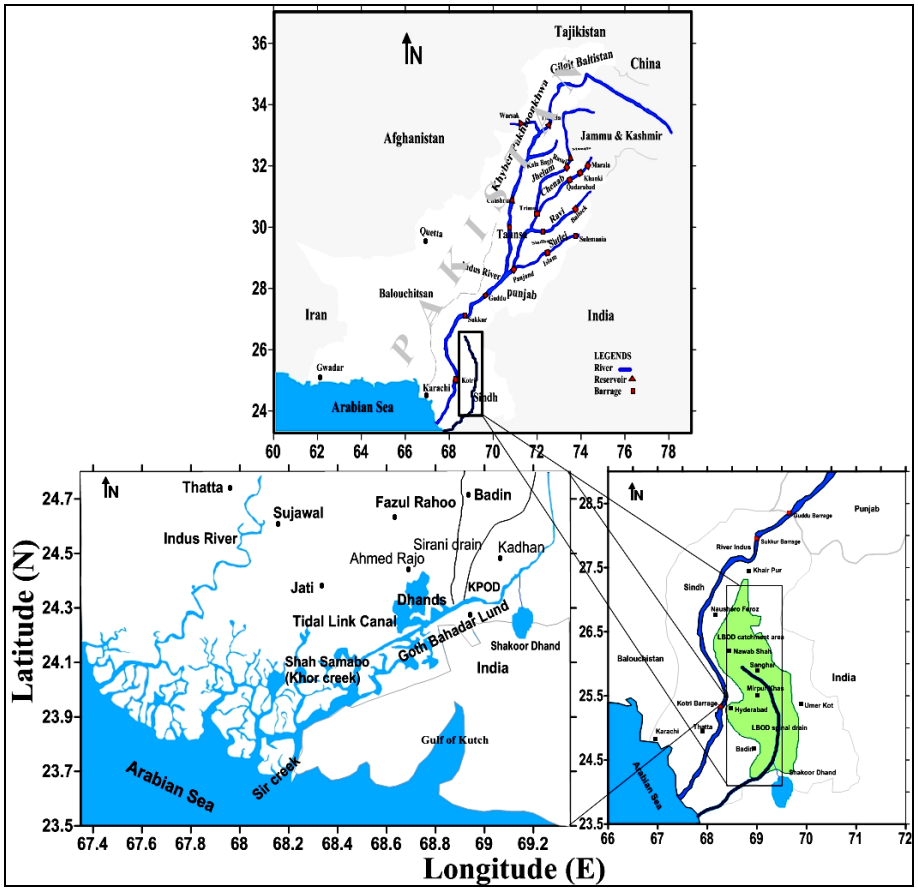


Fig. 1. Map of LBOD with a network of major creeks, tributaries and dhands

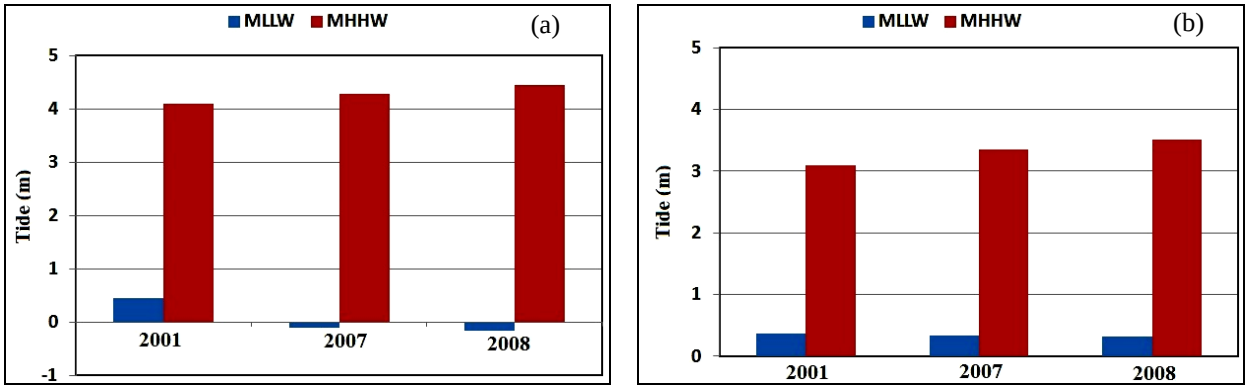
Hence, construction of vast irrigation system on Indus basin created large scale water logging and salinity problems that result in rapid increase in ground water table. It has been reported that about 150 million tons of salt are annually added to the soil-matrix, while about 80 million tons are removed through leaching thus each acre accumulates about 0.6 ton of additional salts every year (Kahlown *et al*., 2002).

The weir controlled irrigation system was also developed in Sindh province to utilize the water of the river Indus. The construction of three barrages at Sukkur, Kotri and Guddu, during 1932 to 1963 in Sindh Province also created water logging and salinity problems.

It is estimated that 1.275 million acres of land in three districts, *i.e*., Nawabshah, Sanghar and MirpurKhas on left bank of the Indus River have been affected by water logging (Alagha *et al*., 2011; Dan Marsh, 1997; LBOD Report, 1996-97). According to Interim Report of Asian Development Bank (ADB, 2005), soil salinity in Sindh province is responsible for 40-60% reduction of major crops grown in recent years.

To reduce the menace of rising ground water and associated problem of water logging and salinity, a network of drainage canals were constructed to drain saline ground water into the Arabian Sea. Among them Left Bank Outfall Drain (LBOD), a man made drainage system on the left bank of Indus River in Sindh Province, remained most talked about project because of its failure to drain the saline ground water into the Arabian Sea. The LBOD was constructed to remove and safely drain saline water from the agricultural land of the districts Nawabshah, Sanghar and Mirpurkhas districts through spinal drain discharged into Pateji and Shakoor lakes.

Later on, with the increased of water inflows, 41 km tidal link canal was constructed to dispose the saline water into sea through Shah Samabo creekclose to Rann of Kutch,former gulf of Arabian sea that has been filled by deltaic deposition(Malik *et al*., 1999; Rajendran and Rajendran, 2001). Gulf of Kutch is a highly dynamic region, where the spring tides reaches up to 6.2 m (Srivastava and John, 1977) and tidal current speed reaching up to 2.5 m/s during southwest monsoon (Muralidharan *et al*., 2015).



Figs. 2(a&b). Yearly comparison of Mean Higher High Water (MHHW) and Mean Lower Low Water (MLLW) at station-1 (a) and station-2 (b)

Tidal Link Canal of the LBOD came into operation in 1995 and it passes through four fresh water lakes; *i.e*., Sanhro, Mehro, Cholri and Pateji, to dispose about 3 million tons of salt and 0.7 million acre-feet of saline water annually into the sea (Alagha *et al*., 2011).

Conversely it left negative impact on dhands and became the cause of destruction of agriculture lands in lower Sindh (Sindh Development Review, 2008-09).

The typical examples are Sujawal and Badin districts of Sindh province where vast area was once fertile but now under the impact of seawater intrusion has been barren. The government of Sindh survey denoted that after 1999 cyclone over 486,000 ha land was eroded within Sujawal and Badin Districts and also displaced and dislocated quarter million people and caused financial loss of over 2 billion dollars (Alagha *et al*., 2011). According the estimations 567,000 ha of land was lost to the sea because of erosion and seawater intrusion (Memon, 2004).

In general the drainage system did not bring effective results because of poor designing, operation and maintenance. Several breaches were occurred in tidal link canal, as a consequence dhands were converted into saline water and seawater intrusion into the link canals was reported to be 80 km upstream (Panhwar, 1999).

As a result, the anthropogenic activities affected the hydrological processes in the lower reaches of tidal link drain and resulted in seawater intrusion. The tidal link drain, LBOD became the cause of seawater intrusion and coastal erosion. Particularly during the southwest monsoon, the neighboring Sea in the south inundates vast area with salt water through tidal link drain. The fresh water lakes as well as agricultural lands and ground water resources have been affected by seawater intrusion and coastal erosion.

Thus, it has become necessary to understand the mechanism of physical processes through sophisticated computer aided techniques, such as coastal ocean models with the simulation of current, waves, storm surge, sediment transport and morphologic changes, in order to analyze, predict and control the saltwater intrusion and coastal inundation.

Therefore, the purpose of this paper is to summarize literature on the impacts/causes and consequences of sea water intrusion and coastal inundation along the LBOD site and to find out the urgent research directions, which may provide useful input for sustainable management of LBOD site and prevent further salinization problems.

2. Data and methodology

For this study along with the summarization of published literature on the LBOD, following efforts were also taken:

Satellite images were compared to analyze the coastline changes; tidal data was obtained from NODC, National Institute of Oceanography (NIO) Pakistan and the agricultural land degradation by coastal flooding record was obtained from Revenue department, Government of Sindh and Pakistan Fisherfolk Forum (PFF). As well as a field survey was conducted to investigate the extent of seawater intrusion in Tidal link drain, LBOD and adjacent dhands. In this connection a boat survey was conducted in tidal link and adjacent dhands for the observation of a longitudinal profile of salinity during the month of April, 2017. Observations were carried out at every 5 km from the RD-117; near the mouth of Tidal link drain, over a distance of 70 km on the upstream side at mid-channel of tidal link and in dhands. Surface and bottom water samples were collected at fourteen stations in tidal link drain and dhands with a 5 L

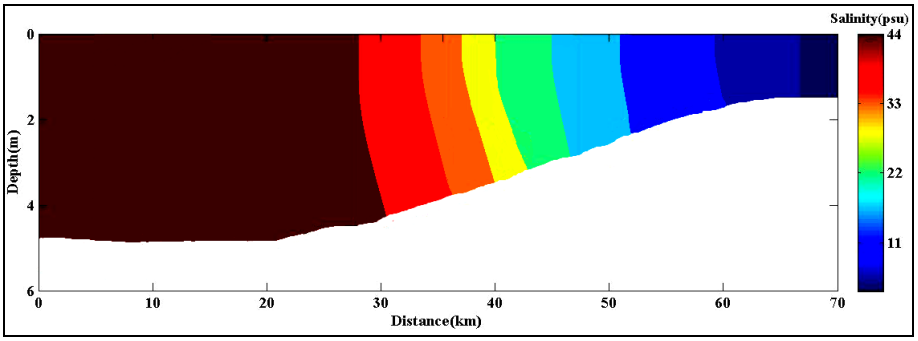


Fig. 3. Longitudinal salinity distributions along the Tidal Link Canal, LBOD during flood phase (22-23 April, 2017)

Niskin bottle to determine the salinity. Salinity was recorded using a water quality meter (Hydrolab Model MS-5); the salinity sensor of the water quality meter was calibrated using standard saline water.

3. Results

3.1. *Tidal fluctuations*

Tides along the Pakistan coast are semidiurnal with two highs and two lows everyday but, significantly vary from each other in tidal heights in daily tidal cycle. They are categorized as HHW (Higher High Water), LHW (Lower High Water), LLW (Lower Low Water) and HLW (Higher Low Water). According to Alagha *et al*. (2011), the maximum tidal amplitude was about 4.8 m and currents speed was quite strong about 1.8 m/sec during ebb tide in tidal link drain; this situation has increased erosion tendencies in the tidal link specifically during the period of SW monsoon.

The tidal data observed by NIO in all four seasons (SW-monsoon, post-monsoon, NE-monsoon and pre-monsoon) during 2007 and 2008 at two selected stations, *i.e*., station-1 about 41 km upstream and station-2 located about 17 km from the mouth (outfall) of the tidal link drain.

This data was analyzed and compared with the historical data collected during the year 2001 available in the NIO (1999-2002).The tidal data variations at station station-1 and 2 are shown in Figs. 2(a&b). The comparison of observations shows some significant changes in the tidal behavior at station-1 and 2 along the Tidal Link Drain. An increasing pattern of tidal range was observed with the passage of time. The Mean Higher High Water (MHHW) and Mean Lower Low Water (MLLW) depicts that the tidal range has been increased about 0.89 m and 0.67 m during the past 8 years at station 1 and 2 respectively as shown in Figs. 2(a&b).

This could possibly be due to the increased erosion and sedimentation in the tidal link drain and creation of more than dozen breaches in the middle section of the tidal link drain. These breaches (openings) allow free exchange of water and a marked increase in seawater intrusion from Arabian Sea. Moreover land subsidence cannot be neglected in this region.

3.2. *Seawater intrusion*

A longitudinal profile of salinity distribution was recorded from mouth to 70 km up stream in the Tidal Link Drain, LBOD during the month of April 2017. The salinity ranged between 3 to 43 psu, maximum (43) and minimum (3) salinity values were observed at 23 and70 km upstream, respectively during flood phase, while salinity was about 41 psu at the mouth of Tidal Link Canal, as shown in Fig. 3. The maximum salinity values were observed at about 28 km upstream, where the large salt water bodies are located, indicating excessive evaporation. According to Harrison *et al*. (1994), tidal channels in Indus Delta are generally hypersaline with salinity range from 38 to 45 psu over the year; however, during the months of August and September the sea water salinity reduces to 26-30 psu due to run off from Indus River. Such adverse hydrographic conditions ultimately affect the delta and enhance degradation of ecosystem.

3.3. *Impacts of saltwater on adjacent dhands (lakes)*

There are four interconnected shallow water lakes (Dhand), *i.e*., Sanehro, Mehro, Pateji and Cholri along the tidal link drain. Before the construction of tidal link drain Cholri Lake receives drain water from other lakes and used to finally drain it to Runn of Kutch, however after the construction of the tidal link drain this natural drainage passage of water from lakes was diverted to the tidal link drain by construction of weir. After the cyclone “2A” in May 1999, the tidal link drain has been severely damaged and there is now a free water exchange between the tidal link drain and adjacent brackish water lakes and the Runn

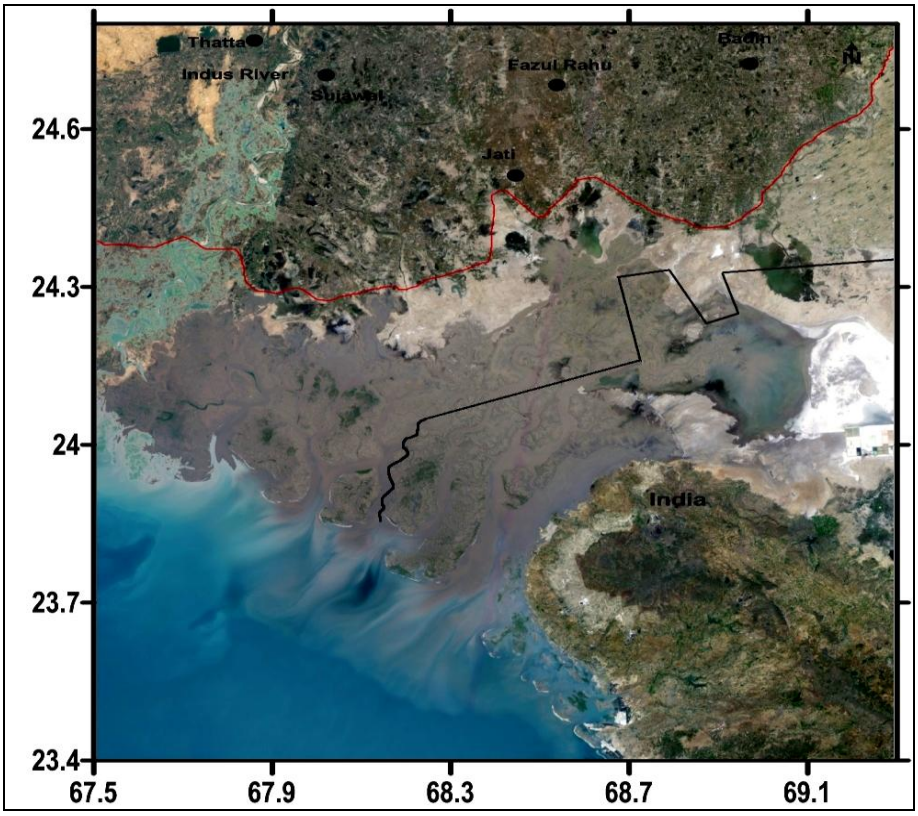


Fig. 4. The multispectral images acquired on February 15, 2016, from GF-1 satellite of China, with 16 m spatial resolution shows the agricultural and residential land in coastal areas of Indus deltaic region is converted into barren land

of Kutch due to creation of breaches in the embankment of tidal link drain as shown in Fig. 1. As a result increased influx of sea water from the tidal link during flood tides, the salinity of these dhands has been increased up to 37 psu.

The observed salinity data of four brackish water lakes varies from 30 to 37 psu, shows the impact of seawater intrusion in all four brackish water lakes from tidal link drain. This exchange of water from tidal link drain has raised salinity level in the Dhands and changed the ecosystem, resulted in decrease of the fish production and species composition. As a result migratory birds, waterfowl and distinctive vegetation are being vanishing (Schneider, 2006).

3.4. *Impacts of saltwater on agricultural lands and groundwater resources*

The Tidal Link Canal is one of the causes of destruction of agricultural land along lower Sindh. During the southwest monsoon when winds are more than 25 knots, the strong storm tides inundate vast area with salt water (Kalhoro *et al.*, 2016). As well as, during the spring tide period, coastal flooding supports tidal infringement over million acres of land in Sujawal and Badin districts, because Tidal Link has gratifying the sea to approach the land, as a result thousands of hectares of the Badin and Sujawal districts to be inundated by seawater. Satellite image in Fig. 4 shows the agricultural and residential land in coastal areas of Sujawal and Badin districts is converted into barren land.

In addition to the above, seawater has been deteriorating the ground waters, according to the Bablani and Soomro (2006), contribution of seawater into ground water which were measured through isotope of oxygen-18 ranges from 18%-31% at Sujawal, 41%-49% at Jati and 83%-92% at Shah Bundar, which are about 75, 45 and 30 km from the coast respectively. The stated scenario has raised problems for local community, because with the reduction in Indus water flows, most of the people in lower Sindh use ground water through tube wells for cultivation of crops, however People are unable to cultivate their lands due to increase of water salinity in ground water resources. The above stated situation has caused dispersal of the local community for their livelihood, because salt-water soaked soils make agriculture difficult.

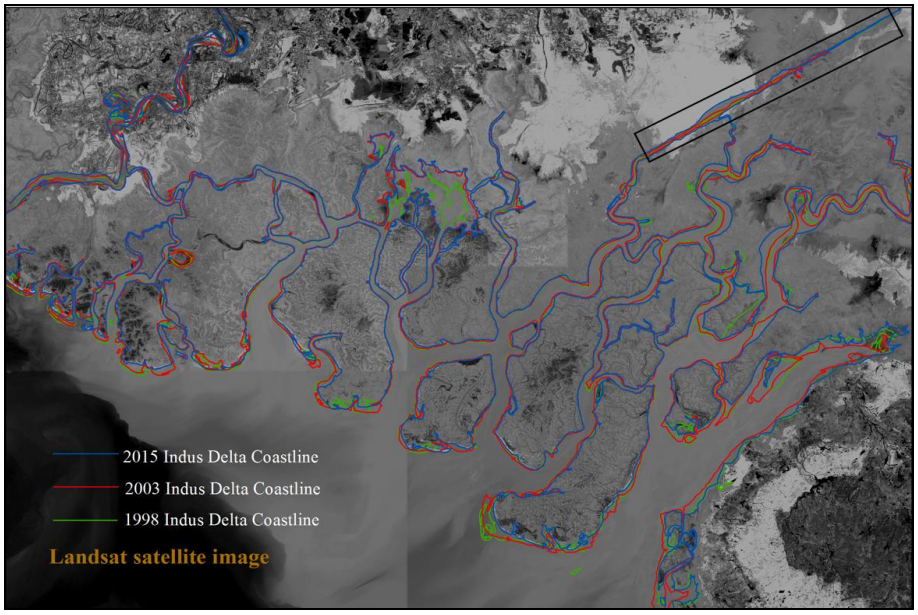


Fig. 5. Changes in the coastline during 1998 to 2015 (green, red and blue lines show the coastline during 1998, 2003 and 2015 respectively, data obtained from NASA)

According to the recent records, 2.945 million acres of fertile land in Sujawal and Badin districts is now affected by coastal flooding and water logging (Table 1).

3.5. *Coastal erosion*

The Satellite images before cyclone (1998) and after cyclone (2003 and 2015) were compared to analyze the coastline changes and to reveal variations in erosion and accretion along the tidal link drain, LBOD site, Indus Delta, as shown in Fig. 5. The images clearly show that erosion and accretion occurred at different regions along the coastline in the past 17 years. Whereas along the tidal link canal average erosion with a rate of 30 m/year is observed (small rectangle in Fig. 5). However, at some places of the Tidal link canal is the most highly eroded with a rate of 50 m/year for the past 17 years was estimated in this region, based on the satellite data.

4. Suggestions for future studies

The LBOD is one of the largest projects in Pakistan for disposal of saline water from agricultural lands to Arabian Sea through Tidal link drain, but the performance of drainage system is not up to expectations. Conversely it left negative social and environmental impacts. After the cyclone 2A several breaches were occurred in tidal link canal and became cause of destruction of agriculture lands in lower Sindh. Because Tidal link canal became a passage of sea to approach the lands and adjacent dhands, due to which whole ecosystem is degrading and sea water intrusion has left heinous environmental & social impacts.

TABLE 1

Land degradation due coastal flooding and water logging

S. No.	Taluka	District	Area (acres)
1.	Jati	Sujawal	626299
2.	Kharochhan	Sujawal	235000
3.	Shah Bandar	Sujawal	2002421
4.	Golarchi	Badin	57764
5.	Badin	Badin	23906
	Total		29,45,390

Therefore, it is necessary to understand the mechanism and processes of sea intrusion and coastal inundation in the near future. However, there is a shortage of detailed field observational data. Meanwhile, many researchers have worked on LBOD and Tidal link canal, but still no modeling effort has been conducted to evaluate the precise extent of coastal inundation and sea water intrusion. However this region is highly dynamics and complex creeks system with varying topography.

Thus, it has become necessary to understand the mechanism of physical processes through systemic field surveys, combining with a coastal ocean model for the accurate estimation of onshore coastal inundation and sea water intrusion to protect the tidal link canal and ecosystem of adjacent dhands and forecast the precise warnings to minimize loss of life and property. Since it is

considered that Indus delta is located on the path of cyclones that are generated in the North Arabian Sea from May to October. During the cyclones of 1986, 1993 and 2001 generated in North Arabian Sea very close to the Sindh coast, storm surge flooded the Indus deltaic region (Haider *et al*., 2008; Rasul *et al*., 2012). To reduce the risks of storm surge and to forecast its occurrence accurately, a high-resolution numerical model is necessary to be developed in which wind-induced sea-level variations are able to be reproduced precisely.

At present, with the development of advanced computer technique, the two-dimensional and/or three-dimensional coastal ocean models have been widely used to better understand and analyze the physical processes in different estuaries all over the world (An *et al*., 2009; Zhao *et al*., 2009; Yang *et al*., 2010; Yoon and Shim, 2013; Bhaskaran *et al*., 2014) and obtained satisfactory results.

Therefore, it has profound importance that updated data sets on different physical, hydrological and hydro-geological variables and parameters need to be collected which have key role to the development of conceptual and numerical model of the LBOD. The long term planning for sustainable management of tidal link drain and adjacent dhands can be achieved if the systematic and focused research directions are conducted. The finding of this study will help to better assess the past and present impacts and future predictions in the region.

5. Conclusions

A thorough overview of the available literature and field observational data on the Tidal Link drain, LBOD has revealed that the hydraulic performance of LBOD is not much effective; conversely, it has left heinous environmental impacts on adjacent lakes and agricultural lands. The main cause could be poor designing construction and maintenance; as well as the catastrophic effects of the cyclone-2A resulted in severe damage to Tidal Link drain, during this event, breaches had occurred in the tidal link. As a consequence manmade Tidal Link is encouraging the sea to approach the land. It is observed that sea water intrusion can reach about 70 km upstream from the mouth of Tidal Link drain, which not only damaged the ecology of dhands, but adversely affects agricultural lands and ground water resources. As a result 2.95 million acres of agricultural land has been affected by coastal flooding and water logging. The exchange of salt water from tidal link has changed the ecosystem of dhands. Meanwhile, fish and bird species are not only reduced in numbers but also in diversity, particularly the migration pattern of the birds has been changed due to changes in the availability of food from estuarine environment into marine fauna and flora. The average erosion rate along the tidal link canal is about 30 m/year; however it reaches up to 50 m/year at some places during the past 17 years. Thus, sea water intrusion and coastal inundation have both caused devastating environmental and social impacts, due to which, the whole ecosystem of the Tidal Link drain, LBOD is facing serious threat.

According to IPCC (2014) mega-delta regions in south and southeast are at high risk due to climate change and billions of people will be affected by the 2050s. Hence in the future, the relative impacts of marine factors (waves and tides) on the Tidal link drain and adjacent area would be more due to sea level rise and coastal flooding. Therefore, necessity and extreme need of today is to rehabilitate the Tidal link canal by mending the affected parts of embankments with coastal protection work and a good drainage system should be planned for smooth movement of the water to the sea. As well as updated data sets on different physical, hydrological and hydro-geological variables need to be collected for the development of conceptual and numerical model of the region.

Acknowledgement

The authors thank the financial support from the National Key Research and Development Program of China (2017YFC1405100) and we appreciate Prof Aiqin SHI from State Key Laboratory of Satellite Ocean Environment Dynamics (SOED) of Second Institute of Oceanography for her kindly processing the remote sensing images.

The contents and views expressed in this research paper are the views of the authors and do not necessarily reflect the views of their organizations.

References

ADB and IUCN, 2002, "Regional Technical Assistance for Coastal and Marine Resources Management and Poverty Reduction in South Asia: Situation Analysis Report, RETA 5974-PAK", Asian Development Bank and International Union for Conservation of Nature.

ADB, 2005, "Sindh Coastal and Inland Community Development Project", Interim Report, Vol II, TA 4525-PAK, Asian Development Bank, 1-253.

An, Q., Wu, Y. Q., Taylor, S. and Zhao, B, 2009, "Influence of the Three Gorges Project on saltwater intrusion in the Yangtze River Estuary", *Environmental Geology*, **56**, 8, 1679-1686.

Bablani, S. A. and Soomro, S. A., 2006, "Evaluation of seawater intrusions in left banksediments of coastal district Thatta, Sindh, Pakistan", Proceedings 1st SWIM-SWICA Joint Saltwater Intrusion Conference, Cagliari-Chia Laguna, Italy - September 24-29, 2006.

Bhaskaran, P. K., Gayathri, R., Murty, P.L.N. and Sen, Debabrata, 2014, "A numerical study of coastal inundation and its validation for Thane cyclone in the Bay of Bengal", *Coastal Engineering*, **83**, 108-118.

Dan Marsh, 1997, "A case study of the left bank outfall drains in Pakistan", Draft working paper presented at the New Zealand Agricultural and Resource Economics society conference, Blenheim 4-5 July.

Haider, K. W., Rasul, G. and Afzaal, M., 2008, "A study on tropical cyclones of the Arabian sea in june 2007 and their connection with sea surface temperature", *Pakistan Journal of Meteorology*, **4**, 8, 37-48.

Harrison, P. J., Snedaker, S. C. Ahmed, S. I. and Azam, F., 1994, "Primary producers of the arid climate mangrove ecosystem of the Indus River Delta, Pakistan: An overview", *Journal of Tropical Ecology*, **35**, 2, 155-184.

IPCC, 2014, "Intergovernmental panel on climate change (IPCC) fifth assessment", working group 2 report.

Kahlown, M. A., Azam, M. and Blackwell, J., 2002, "Prospects of Sequential Biological Concentration for Salinity-Management in Pakistan", Quarterly Science Vision, **8**, 1, July-Sept., 79-86.

Kalhoro, N. A., He, Z., Xu, D., Faiz, M., Yafei, L.V., Sohoo, N. and Bhutto, A. H., 2016, "Vulnerability of the Indus River Delta of the North Arabian Sea, Pakistan", *Global NEST Journal*, **18**, 3, 599-610.

LBOD (Left Bank Outfall Drainage), "Quarterly monitoring reports", For the period from July 1996 to June 1997. A report prepared by Mott MacDonald Int. Consultants for Water & Power Development Authority, Government of Pakistan.

Malik, J. N., Merh, S. S. and Sridhar, V., 1999, "Palaeo-delta complex of Vedic Sarasvati and other ancient rivers of northwestern India", *Geological Society of India Memoirs*, **42**, 163-174.

Memon, A. A., 2004, "Evaluation of Impacts on the Lower Indus River Basin Due to Upstream Water Storage and Diversion", Proceedings, World Water& Environmental Resources Congress, ASCE-EWRI, Salt Lake City, Utah, June 27 - July 1.

Muralidharan, J., Ganesh Kumar, B. and Pravin D. K., 2015, "Sediment transport study along Gulf of Kachchh - A Numerical and Geospatial approach", *International Journal of Applied Engineering Research*, **10**, 55, 4291-4296.

N. I. O. Report, 1999-2002, "Hydraulic Monitoring of the Tidal Link Drain", *Final Technical Report*, National Institute of Oceanography, Karachi, Pakistan.

Panhwar, M. H., 1999, "Seepage of water of the River Indus and occurrence of fresh ground water in Sindh", 180-197, In: *The Indus River (Biodiversity, Resources, Humankind)*, Azra Meadows & P. Meadows (Eds.) Oxford University Press, 1-441.

Rajendran, C. P. and Rajendran, K., 2001, "Characteristics of deformation and past seismicity associated with the 1819 Kutch earthquake, Northwestern India", *Bulletin of the Seismological Society of America*, **91**, 3, 407-426.

Rasul, G., Mahmood, A., Sadiq, A. and Khan, S. I., 2012a, "Vulnerability of the Indus delta to climate change in Pakistan", *Pakistan Journal of Meteorology*, **8**, 16, 89-107.

Rizvi, M., 2001, "Forecasting water flows in Pakistan's Indus River", The International Development Research Center, http://idrc.ca/en/ev-5441-201-1-DO_TOPIC.html.

Salam Khalid Al-Agha, Inamullah Bhatti, Hossam Adel Zaqoot, Shaukat Hayat Khan and Abdul Khalique Ansari, 2011, "Physico-Chemical Environment of Coastal Areas in the Vicinity of Left Bank Outfall Drainage (LBOD) and Tidal Link Drain (TLD) in Sindh, Pakistan after Cyclone 2a", *International Journal of Civil and Environmental Engineering*, **3**, 3, 150-155.

Schneider, A. K., 2006, "National Drainage Program project in Pakistan", International Rivers Network (IRN) Comment on the Inspection Panel Report and Management response.

Sindh Development Review, 2008-09, "Indus delta: planning and development department", Government of Sindh, www.sindh pnd.gov.pk , 211-214.

Srivastava, P. S. and John, V. C., 1977, "Current Regime in the Gulf of Kutch", *Indian Journal of Marine Sciences*, **6**, 39-48.

Yang Zhaoqing, Kathryn L. Sobocinski, Heatwole Danelle, Tarang Khangaonkar, Ronald M. Thom and Roger Fuller, 2010, "Hydrodynamic and ecological assessment of nearshore restoration: A modeling study", *Ecological Modelling*, **221**, 7, 1043-1053.

Yoon, J. J. and Shim, J. S. 2013, "Estimation of storm surge inundation and hazard mapping for the southern coast of Korea", Proceedings 12th International Coastal Symposium (Plymouth, England), *Journal of Coastal Research*, Special Issue No. **65**, 856-861.

Zhao, R., Yang, Z. F., Sun, T., Chen, B. and Chen, G. Q., 2009, "Freshwater inflow requirements for the protection of the critical habitat and the drinking water sources in the Yangze River Estuary, China", *Communications in Nonlinear Science and Numerical Simulation*, **14**, 5, 2507-2518.