J. Ocean Univ. China (Oceanic and Coastal Sea Research)
DOI 10.1007/s11802-017-3350-4
ISSN 1672-5182, 2017 16 (6): 1055-1060
http://www.ouc.edu.cn/xbywb/
E-mail:xbywb@ouc.edu.cn

Assessment of Sea Water Inundation Along Daboo Creek Area in Indus Delta Region, Pakistan

ZIA Ibrahim[1), 2)], ZAFAR Hina[2)], SHAHZAD Muhammad I.[3), *], MERAJ Mohsin[3)] and KAZMI Jamil H.[2)]

1) *National Institute of Oceanography (NIO), Karachi* 75600, *Pakistan*
2) *Department of Geography, University of Karachi* 75270, *Pakistan*
3) *Earth & Atmospheric Remote Sensing Laboratory (EARL), Department of Meteorology, COMSATS Institute of Information Technology (CIIT), Park Road, Islamabad* 45550, *Pakistan*

(Received November 11, 2016; revised January 16, 2017; accepted April 24, 2017)

Abstract Indus Deltaic Region (IDR) in Pakistan is an erosion vulnerable coast due to the high deep water wave energy. Livelihood of millions of people depends on the fisheries and mangrove forests in IDR. IDR consists of many creeks where Daboo is a major creek located at southeast of the largest city of Pakistan, Karachi. Unfortunately, there has been no detailed study to analyze the damages of sea water intrusion at a large temporal and spatial scale. Therefore, this study is designed to estimate the effects of sea water inundation based on changing sea water surface salinity and sea surface temperature (SST). Sea surface salinity and SST data from two different surveys in Daboo creek during 1986 and 2010 are analyzed to estimate the damages and extent of sea water intrusion. Mean salinity has increased 33.33% whereas mean SST decreased 13.79% from 1987 to 2010. Spatio-temporal analysis of creek area using LANDSAT 5 Thematic mapper (TM) data for the years 1987 and 2010 shows significant amount of erosion at macro scale. Creek area has increased approximately 9.93% (260.86 m^2 per year) which is roughly equal to 60 extensive sized shrimp farms. Further Land Use Land Cover (LULC) analyses for years 2001 and 2014 using LANDSAT 7 Enhanced Thematic Mapper Plus (ETM+) has indicated 42.3% decrease in cultivated land. Wet mud flats have spread out at the inner mouth of creek with enormous increase of 123.3%. Significant sea water intrusion has increased the area of barren land by 37.9%. This also resulted in overall decrease of 6.7% in area covered by mangroves. Therefore, this study recorded a significant evidence of sea water intrusion in IDR that has caused serious damages to community living in the area, economical losses. Additionally, it has also changed the environment by reducing creek biological productivity as reported by earlier studies over other regions of the world.

Key words sea water intrusion; SST; salinity; Ambro creek; CTD

1 Introduction

Coastal areas can be affected by human activities such as sediment excavation, river modification and coastal construction in addition to natural processes such as relative sea level rise and frequent storms (Morton, 2003; Werner *et al*., 2012). IDR is facing geomorphological changes in all areas along its major and minor creeks in the form of erosion and reduced rate of sediment deposition from Indus River during post-damming (Giosan *et al*., 2006). The IDR ranked the fourth highest in receiving average wave energy as compared with other world famous deltas, for example Nile, Mississippi Niger, Ganges and Ebro deltas (Wells and Coleman, 1984). These high-energy waves are producing a straight shoreline, redistributing sediments and erosion in the IDR (Wells and Coleman, 1984). Increasing sea level followed by intrusion of sea water is claiming more land and changing the geomorphology in IDR (Chandio *et al*., 2011). This also decreases the volume of fresh water along the coastal areas (Lu *et al*., 2014). Human activities such as construction of dams also have severely affected the IDR by reducing sediment supply and increasing erosion (Smith and Abdel-Kader, 2014; Yang *et al*., 2005).

It is observed that ebb current has higher velocity than flooding during northeast and southwest monsoon periods, so it increases the erosion in IDR particularly during the periods of strong summer monsoon (N.I.O. Report, 2000). It can also cause the dispersion of soft sediments along the creek banks under the influence of certain tidal rhythm which can further increase the depth and width of creeks. Additionally, the extent of erosion increases along with sea level rise which may either be due to increased mean SST causing water to expand and/or due to ice melting around the globe after global warming (Ranasinghe *et al*., 2011).

Aforementioned facts change the geomorphology of the coastal area such as IDR (Hinkel *et al*., 2013) which is the major source for livelihood of millions of people in

* Corresponding author. E-mail: imran.shahzad@connect.polyu.hk

terms of fisheries and mangrove forests. Like IDR, sudden as well as gradual sea water intrusion in many deltaic regions have caused devastating damages to health (Khan *et al*., 2011), infrastructure (Antonellini *et al*., 2008) and ecology (Felisa *et al*., 2013). IDR consists of many creeks and among them Daboo is a major creek (Fig.1). Daboo creek is located at 55 km southeast of the largest city of Pakistan, Karachi. This creek is linked with several small creeks on many locations where depth may vary from 5 to 15 m. Unfortunately, there has been no detailed study to analyze the damages of sea water intrusion at a large temporal and spatial scale. Therefore, this study is designed to analyze and observe the effects of sea water inundation that can change the width of creek. This study also aims to explore the response of sea water surface salinity and SST on the sea water intrusion. This study also focuses on the assessment of damages due to sea water intrusion along the Daboo creek.

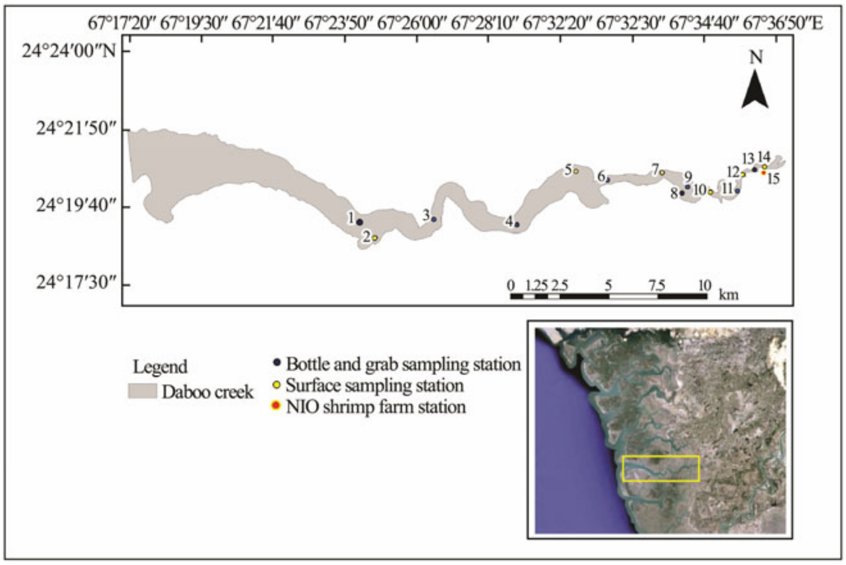

Fig.1 Map of study area showing the extent of Daboo creek with marked locations of 15 sampling sites to record daily mean values of SST and sea surface salinity.

2 Study Area

Starting from landside, Daboo creek is known as Ambra or Ambro creek in local language (Fig.1). Ambro creek is transformed into a major creek as it approaches the sea and is then named as Daboo creek. Daboo creek is approximately 39.35 km long from land to sea mouth and is about 3.91 km wide at entrance to the sea. Ghora Bari shrimp farm station of National Institute of Oceanography (NIO), Pakistan is also situated at the start of Ambro creek (Fig.1). NIO shrimp farm has several ponds but now large area of the farm has been eroded due to continued erosion over the years. Ambro creek is linked with several commercial harvesting farms of crabs, shrimps and different types of fish. Since decades, Ambro creek has been used for fishing by local villagers but not now due to changes in salinity level. This also caused huge financial losses to Shrimp farm station of NIO. Although lots of vegetation has vanished from the vicinity of creek, some patches of mangrove are still alive indicating the presence of fresh water intake in the creek from upper parts.

3 Data and Methodology

This study uses the data of daily mean SST and salinity obtained during field surveys in 1986 and 2010 along the Daboo creek (Figs.1 and 2). Total 15 stations were deployed during 2010 compared to 9 stations in 1986 starting from mouth of creek at open sea towards inland. Salinity and temperature data in this study are obtained using Conductivity, Temperature and Depth (CTD) instrument where salinity is measured in terms of electrical conductivity of sea water (Gaillard *et al*., 2015). Unfortunately, there was no LANDSAT image available during the surveyed year of 1986. Hence, first available cloud free image of LANDSAT 5 TM at Path 152 and Row 043 in November 1987 is compared with the same season image in December 2010. In addition, LANDSAT 7 ETM+ images also at Path 152 and Row 043 in November 2001 and January 2014 are also used for identifying the spatio-temporal changes in Land Use Land Cover (LULC) due to erosion using classification schemes distribution. Geographical Information System (GIS) techniques are used to extract and highlight the LULC changes in the peripheries of creek during this time.

4 Results and Discussion

The significant transient changes in temperature and salinity are observed during 2010 compared to 1986 (Fig.3). Minimum salinity in 2010 is recorded as 36 which is 27.21% more than the value of 28.3 in 1986 indicating significant effect of sea water intrusion. This is also indicated by the increase of 15.72% in maximum values recorded during 2010 (41) and 1986 (35.43). Compared to 29.4 in 1986, the average value of salinity is 39.2 in 2010 indicating and alarming 33.33% increase which is almost 1.4% increase per year. It is interesting to note that there is no drastic decrease in salinity even almost 35 km away from open sea starting from first to fifteenth station. Fig.3 clearly shows the salinity increase in coastal sea water along the Daboo creek since 1986 to 2010 which may be due to anthropogenic activities and sea level rise (Liu and Liu, 2014). Increase in surface salinity may also be aggravated by the decrease in incoming fresh water discharging from river Indus, which also results in in sea level rise and increased sea water intrusion in the coastal areas (Chang *et al*., 2011).

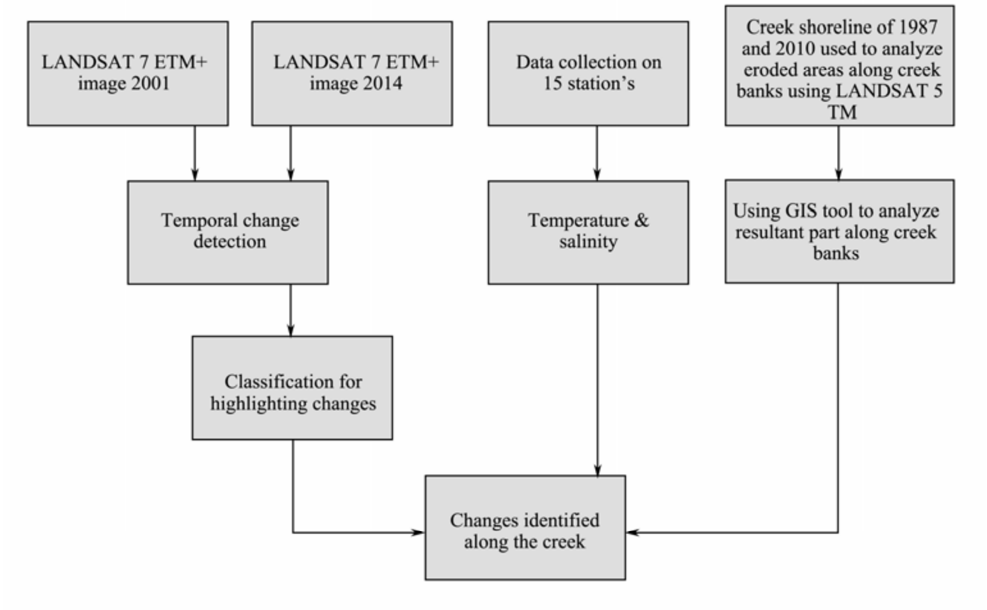

Fig.2 Methodological flow diagram used to identify the spatiotemporal changes along the Daboo creek using images from LANDSAT 5 TM and LANDSAT 7 ETM+ at Path152 and Row 043.

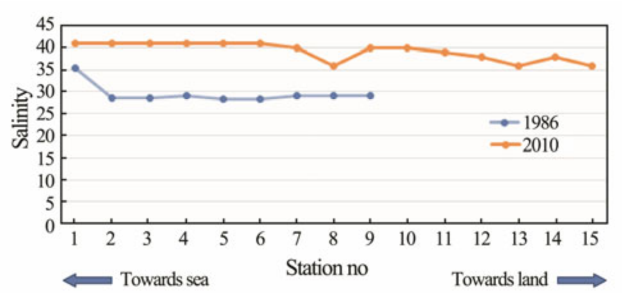

Fig.3 Daily mean sea surface salinity values recorded during field surveys in 1986 and 2010 over 15 ground stations along the Ambro creek. The location of station number 01 is very close to the open sea and station number 15 is located far inland as shown in Fig.1.

Ocean salinity significantly depends on SST because increase in SST decreases density of sea water and hence decreases salinity (Bae *et al*., 2014). Therefore, SST is also recorded during the field surveys done in 1986 and 2010 along the Daboo creek at the same sampling stations that are used to record salinity (Fig.4). Minimum SST during 2010 is recorded as 27℃ which is 5.26% less than the 28.5℃ in 1986. Similarly, a decrease of 8.08% in maximum SST is recorded during 2010 (33℃) and 1986 (35.9℃). Average value of SST in 2010 is 28.70℃, compared to 33.29℃ in 1986 indicating a significant plunge of 13.79%. Like salinity (Fig.3), there is also no remarkable change in SST between the first and fifteenth ground observation station which is almost 35 km away from open sea. Although, Fig.4 clearly shows a decrease of SST in coastal sea water along the Daboo creek during 1986 and 2010, earlier studies have reported an increasing trend in SST for overall Arabian Sea and its coastal area including Indus delta (Rana *et al*., 2014; Kumar and Prasad, 1999). The decrease in SST observed in this study may be attributed to the use of mean daily SST and might be randomly valid only for those particular field days of 2010.

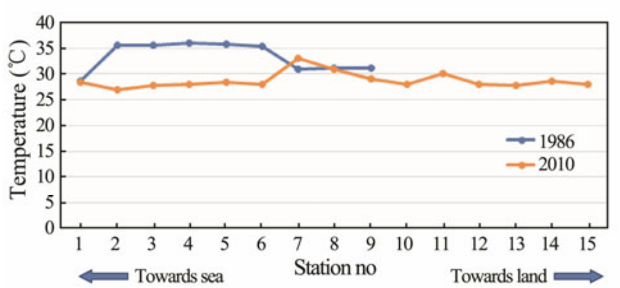

Fig.4 Daily mean SST (℃) values recorded during field surveys in 1986 and 2010 over 15 ground stations along the Ambro creek. The location of station 1 is very close to the open sea and station 15 is located far inland as shown in Fig.1.

It is also important to note that SST near the open sea is 28.5℃ in 1986 with a sudden jump to approximately 35℃ at the second station (Fig.4). Temperature then remained above 35℃ with the maximum value of 35.9℃ and again dropped to near 31℃. Overall 20.61% decrease in temperature is recorded. However, there is an inverse variation trend in SST along the same stations during 2010 (Fig.4). Such variation is not evident in salinity (Fig.3), indicating spatio-temporal variations of fresh and sea water along the Daboo creek which is also confirmed by the presence of mangroves in patches. Moreover, sharp change in SST during 2010 at the station number 07 in Fig.4, may be due to time of sampling that was during low tide because retreating tidal current can create a warm surface layer as the tide ebbed (Souza and Pineda, 2001). This warm layer might also have a decreased salinity as observed in Fig.3. Overall, mean fractional change in SST (13.79%) is less than mean fractional change in salinity (33.33%) in Daboo creek during 1987 and 2010.

After many field surveys by NIO over the past years, it is observed that the situation of Indus deltaic creek system has extremely changed over decades such that sea water intruded on the agricultural lands to change dimensions of creek. It has also been observed that fresh water availability and building structure are also damaged along the creek. Temporal analysis for 1987 and 2010 creek coastline precisely reflects these changes along both sides of the Daboo creek (Fig.5). Changes along the creek are in the form of land loss to sea because the creek temporally changed its course and eroded several aquaculture ponds. Creek water also intruded erratically causing massive soil salinization at some places. Fig.5 clearly shows many minor water channels along which sea water may intrude. Creek area has increased by 9.93% from 1987 (60.4 km^2) to 2010 (66.4 km^2), which is roughly equal to 60 extensive sized shrimp farms. This resulted in 40% decrease for size of NIO's shrimp farm from 0.41 km^2 to 0.24 km^2 (personal communication with officials of NIO). Therefore, it is very alarming to notice that sea water intruded at the rate of approximately 260.86 m^2 per year from 1987 to 2010.

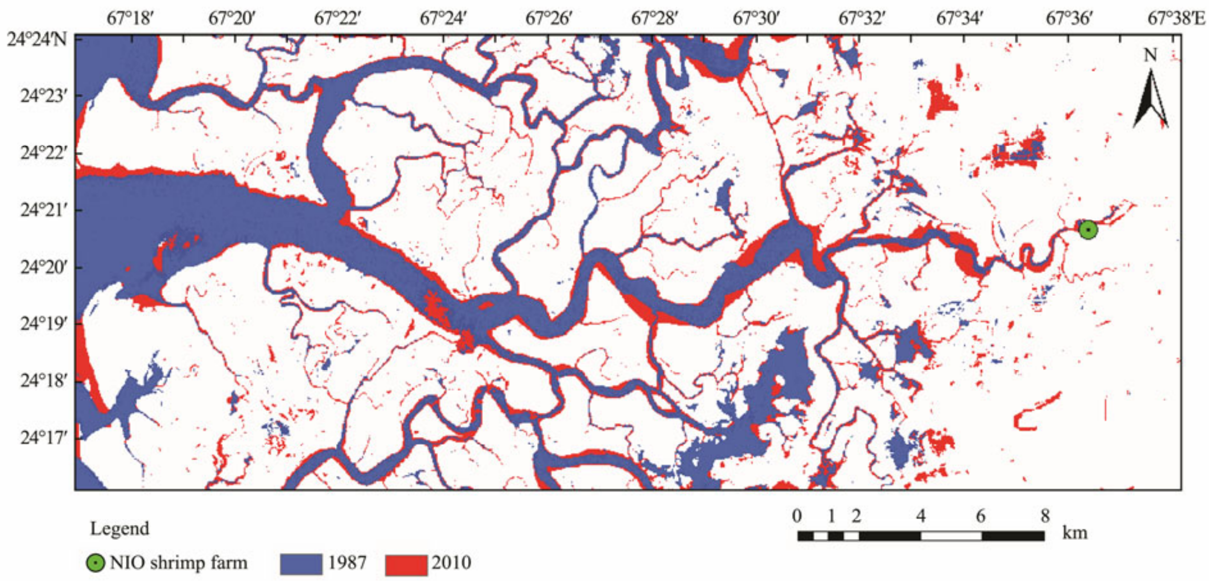

Fig.5 Thematic change in creek areas from 1987 (blue color) to 2010 (red color).

Spatio-temporal changes in LULC are qualitatively analyzed using supervised classification for 2014 (Fig.6a) and 2001 (Fig.6b), then these changes are further quantified in Fig.7. Although, there is not much change (−4.9%) in area covered by water (white color) during 2001 and 2014 but there is a significant shift of mangroves from dense (light pink) to sparse (dark pink) coverage. Area covered by dense (sparse) mangroves has decreased (increased) from 55 to 47 km^2 (35 to 37 km^2) which is equivalent to the 6.7% decrease in area covered by mangroves. It is evident that cultivated vegetation (dark green color) covered larger area (52 km^2) in 2001 than in 2014 (30 km^2), confirming the impact of sea water intrusion in study area that has decreased by 42.3% in the area earlier available for cultivation. This is also evident from the increase of 37.9% in covered area of barren land (light green) from 29 to 40 km^2 in 2001 and 2014 due to sea water intrusion during tidal flooding. There has also been significant increase of 29.7% in the extent of mud flats from 2001 to 2014. Wet mud flats (light blue color) has increased by 123.3% from 86 to 192 km^2 whereas dry mud flats (dark blue color) decreased by 39.7% from 116 to 70 km^2. Hence more significant damages to LULC are observed in 2014 than 2001. A clear decrease in sand dunes (dark red color) is evident, also indicting sea water intrusion in creeks. Therefore, there is significant evidence that sea water intrusion in IDR has caused serious damages to community living in the area, economical losses and has changed the environment by reducing creek biological productivity as reported by earlier studies over other regions of the world (Milliman *et al*., 1989; Vineis *et al*., 2011).

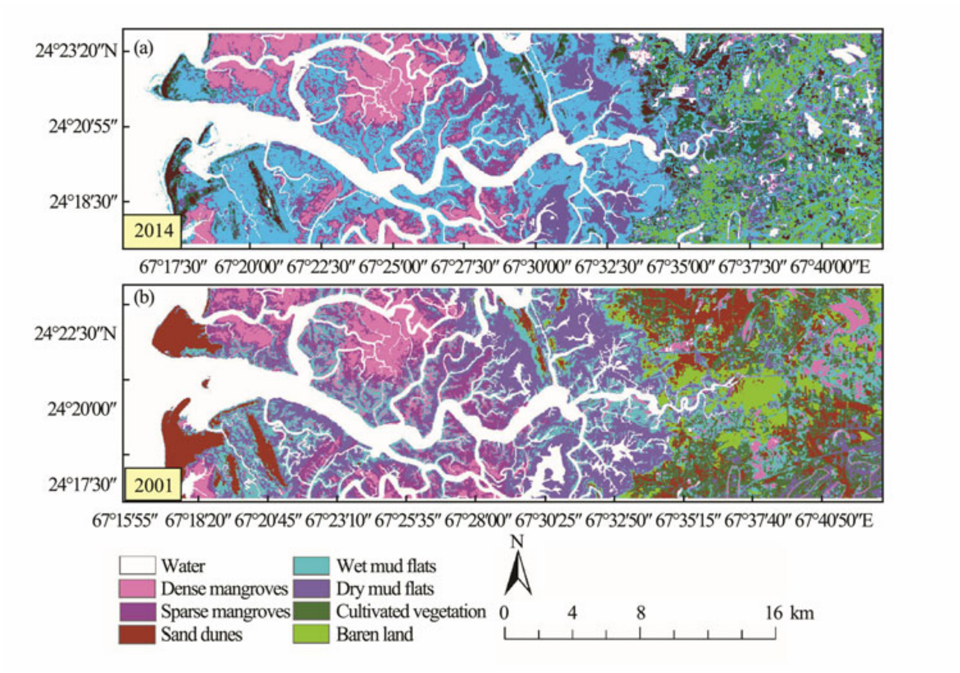

Fig.6 LULC map based on LANDSAT 7 ETM+ images in (a) 2014 and (b) 2001 indicating major changes in the Daboo creek and its vicinity.

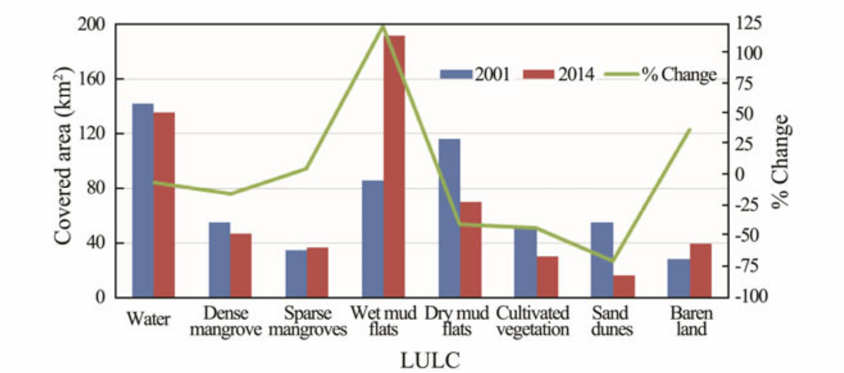

Fig.7 Percentage changes of each LULC parameter from 2001 to 2014.

5 Conclusions

Sea surface salinity and SST data from two different surveys during 1987 and 2010 along with LANDSAT 5 TM data is analyzed to estimate the damages and extent of sea water intrusion in the Daboo creek. Mean salinity has increased 33.33% since 1987 to 2010 from 29.4 to 39.2 whereas mean SST decreased 13.79% during the same period from 33.29℃ to 28.7℃. Percentage increase in salinity is significantly greater than percentage decrease in SST. Creek area has increased 9.93% (approximately 260.86 m^2 per year) from 1987 (60.4 km^2) and 2010 (66.4 km^2). This also has resulted in decrease of 40% in area covered by the shrimp farm of NIO. Many areas are now covered with sparse mangroves where there were dense mangrove plantations before. Cultivated vegetation has decreased by 42.3% whereas area of barren land has increased by 37.9%. Area of wet mud flats has increased by 123.3% whereas dry mud flats decreased by 39.7%. Therefore, there is significant evidence that sea water intrusion in IDR has caused serious damages to community living in the area, economical losses and also has changed the environment by reducing creek biological productivity as reported by earlier studies over other regions of the world. Policy makers should pay attention to implement sustainable and resilient plans to avoid future geographic and socio-economic damages due to sea water intrusion along the Daboo creek.

Acknowledgement

The authors would like to thank National Institute of Oceanography (NIO), Karachi, Pakistan for providing the *in-situ* data and department of Geography at the University of Karachi for their research input.

References

Antonellini, M., Mollema, P., Giambastiani, B., Bishop, K., Caruso, L., Minchio, A., Pellegrini, L., Sabia, M., Ulazzi, E., and Gabbianelli, G., 2008. Salt water intrusion in the coastal aquifer of the southern Po Plain, Italy. *Hydrogeology Journal*, **16**: 1541-1556, DOI: 10.1007/s10040-008-0319-9.

Bae, S. W., Lee, K. E., Park, Y., Kimoto, K., Ikehara, K., and Harada, N., 2014. Sea surface temperature and salinity changes near the Soya Strait during the last 19 ka. *Quaternary International*, **344**: 200-210.

Chandio, N. H., Anwar, M. M., and Chandio, A. A., 2011. Degradation of Indus delta, removal mangroves forestland its causes: A case study of Indus river delta. *Sindh University Research Journal (Science Series)*, **43** (1): 67-72.

Chang, S. W., Clement, T. P., Simpson, J. M., and Lee, K. K., 2011. Does sea-level rise have an impact on saltwater intrusion? *Advances in Water Resources*, **34**: 1283-1291.

Felisa, G., Ciriello, V., and Federico, V., 2013. Saltwater intrusion in coastal aquifers: A primary case study along the adriatic coast investigated within a probabilistic framework. *Water*, **5** (4): 1830-1847.

Gaillard, F., Diverres, D., Jacquin, S., Gouriou, Y., Grelet, J., Menn, M. L., Tassel J., and Reverdin, G., 2015. Sea surface temperature and salinity from French research vessels, 2001–2013. *Scientific Data*, **2**: 1-9.

Giosan, L., Constantinescu, S., Clift, P. D., Tabrez, A. R., Danish, M., and Inam, A., 2006. Recent morphodynamics of Indus delta shore and shelf. *Continental Shelf Research*, **26**: 1668-1684.

Hinkel, J., Nicholls, R., Tol, R., Wang, Z., Hamilton, J., Boot, G., Vafeidis, A., McFadden, L., and Klein, R., 2013. A global analysis of erosion of sandy beaches and sea-level rise: An application of DIVA. *Global and Planetary Change*, **111**: 150-158.

Khan, A. E. H., Ireson, A., Kovats, S., Mojumder, S. K., Khusru, A., Rahman, A., and Vineis, P., 2011. Drinking water salinity and maternal health in coastal Bangladesh: Implications of climate change. *Environmental Health Perspectives*, **119** (9): 1328-1332.

Kumar, S. P., and Prasad, T. G., 1999. Formation and spreading of Arabian Sea high-salinity water mass. *Journal of Geophysical Research*, **104**: 1455-1464.

Liu, W. C., and Liu, H. M., 2014. Assessing the impacts of sea level rise on salinity intrusion and transport time scales in tidal estuary, Taiwan. *Water*, **6** (2): 324-344.

Lu, C., Xin, P., Li, L., and Luo, J., 2014. Seawater intrusion in response to sea-level rise in a coastal aquifer with a general-head inland boundary. *Journal of Hydrology*, **522**: 135-140.

Milliman, J. D., Broadus, J. M., and Gable, F., 1989. Environmental and economic implications of rising sea level and subsiding deltas: The Nile and Bengal examples. *Royal Swedish Academy of Sciences*, **18** (6): 340-345.

Morton, R. A., 2003. An overview of coastal land loss: With emphasis on the southeastern united states. *USGS Open Report*. St. Petersburg, 1-29.

National Institute of Oceanography (N.I.O), 2000. The impact of cyclone 2A on the tidal link drain and adjacent areas based on the historical data. *National Institute of Oceanography (N.I.O) Report*. Karachi, Pakistan, 1-66.

Rana, A. S., Zaman, Q., Afzal, M., and Haroon, M., 2014. Characteristics of sea surface temperature of the Arabian Sea coast of Pakistan and impact of tropical cyclones on SST. *Pakistan Journal of Meteorology*, **11** (2): 61-70.

Ranasinghe, R., Callaghan, D., and Stive, M., 2011. Estimating coastal recession due to sea level rise: Beyond the Bruun rule. *Climatic Change*, **110** (3): 561-574.

Smith, S., and Abdel-Kader, A., 2014. Coastal erosion along the Egyptian Delta. *Journal of Coastal Research*, **4** (2): 245-255.

Souza, A., and Pineda, J., 2001. Tidal mixing modulation of sea surface temperature and diatom abundance in southern California. *Continental Shelf Research*, **21** (6-7), 651-666.

Vineis, P., Chan, Q., and Khan, A., 2011. Climate change impacts on water salinity and health. *Journal of Epidemiology and Global Health*, **1** (1): 5-10.

Wells, J., and Coleman, J., 1984. Deltaic morphology and sedimentology, with special reference to the Indus River delta. *Marine Geology & Oceanography of Arabian Sea & Coastal Pakistan*, **TR–424**: 85-100.

Werner, A., Bakker, M., Post, V., Vandenbohede, A., Lu, C., Ataie-Ashtiani, B., and Simmons, C. T., 2012. Seawater intrusion processes, investigation and management: Recent advances and future challenges. *Advances in Water Resources*, **51**: 3-26.

Yang, S., Zhang, J., Zhu, J., Smith, J., Dai, S., Gao, A., and Li, P., 2005. Impacts of dams on Yangtze River sediment supply to the sea and delta intertidal wetland response. *Journal of Geophysical Research*, **110**: F03006, DOI: 10.1029/2004JF 000271.

(Edited by Chen Wenwen)