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Geospatial analysis of creeks evolution in the Indus Delta, Pakistan using multi sensor satellite data

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A B S T R A C T

Sea level rise (SLR) in response to looming climate change is being considered as a major impediment to coastal areas. Acute wave activities and tidal propagations of semi-diurnal to mixed type are impairing the morphology of the Indus Delta in Pakistan. In this study a synthetic approach has been adopted using multi sensor satellite and ground data in order to integrate the individual effect of topography, oceanic activities and vegetative canopy for deduction of a synergic impact over the morphology of the Indus Delta creeks system from 1972 to 2017. Geomorphologic anomalies in the planform of fourteen major creeks were explored. Spatiotemporal variations suggested that a substantial amount of the delta alluvium had been engulfed by the Arabian Sea. On average, the creeks located on the right side of the Indus River were relatively less wide (3.9 km) than those of on the left side (5.2 km). Zonal statistics calculated with topographic position index (TPI) enabled to understand the tide induced inundation extents. The mangrove canopy on the right side was found greater, which is why tidal basins on that side experienced less erosive activities. Thus, it could be maintained that the coastal sedimentary processes may be monitored effectively with the remotely sensed data and temporal pattern of changes can be quantified for future planning and mitigation of adverse effects.

1. Introduction

The interaction between land and oceans has always been of dynamic nature (Sarmiento et al., 2016). Coastal areas have been severely affected by the ongoing warming of the global climate in the form of mean sea level rise and extensive erosion due to more frequently occurring storms and cyclones. The earth is experiencing continuous warming since 1980 (IPCC, 2013). Glacial retreat and thermal expansion of the sea water in response to global warming is rendering undesirable eustatic sea level rise. This phenomenon has disturbed the so-called equilibrium between land and oceans. Evidences across the globe suggest that sea level rise (SLR) has accelerated at a notable rate and low-lying settlements in coastal systems are under a great threat of calamities (Spencer et al., 2016; Leonard et al., 2017; Parekh et al., 2017). Ecological and geomorphological transitions along their interfaces have become more frequent over short to the long timescales (Ryu et al., 2008).

Basically, the spatial arrangement of the wetlands and topographic orientation of the tidal basins determine their tidal hydrology and inundation patterns (Li et al., 2014; Liu et al., 2013; Kang and Ding, 2013) and correspondingly dominance of flood or ebb tides determine the channel morphology (Tambroni et al., 2017). Whilst, physiographic features of the landscape and contextual placement of the flora plays a pivotal role in the geomorphologic evolution of the coastal systems (Daidu et al., 2013). Minimization of uncertainties in understanding and prediction of their mutual interactions is a core issue in coastal management (Grosholz, 2002; Cash and Moser, 2000; Dalyander et al., 2016).

Indus Delta falls into the category of those deltas of the world

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which are more vulnerable to SLR (UNEP-DHI and UNEP, 2016). Heavy fluvial fluxes of the Indus River originating from the Himalayan range used to drain into the Arabian Sea through numerous natural waterways. However, since 1861 until now the number of natural waterways has decreased from 17 to 1 due to artificial impoundments, extensive upstream abstractions, and confinement of the river course within man-made levees (Syvitski et al., 2013). Such anthropogenic perturbations have significantly weakened its natural regimes, and consequently, oceanic activities along the Sindh coast are exacerbating the morphological setting of the delta alluvium through unprecedented erosion in its creeks network (Inam et al., 2007; Mahar, 2010).

Geographically, the Indus River bisects the Lower Indus Basin in the Sindh province of Pakistan into two major zones. The right (western) side is comprised of irrigated and dry lands bounded within the right bank of the river and Khirther mountains of the Sulaiman range while the left (eastern) side is also irrigated plain ranging from the left bank to the Thar desert. Both sides, connect with the Indus delta that borders the Sindh coast in the south of the province. Topographically, the terrain of the province is flat where nearly one-fifth of the canal command areas face major issues of waterlogging and soil salinity (SIDA, 2013). Rehabilitation projects are underway to mitigate the problems for sustainable agriculture that includes (1) the Left Bank Outfall Drain (LBOD) which was completed in 1997 for disposal of agricultural and industrial effluents into the Arabian sea, revival of natural waterways, mangroves plantation, rehabilitation of wetlands, and forest plantation with drainage water, (2) the Right Bank Outfall Drain (RBOD) is a project of disposal of effluents from province Baluchistan to the sea through province Sindh and more than 50% of its construction work is completed.

Wetlands ecosystem of the Indus Delta supports a wide range of biodiversity like plants, birds, fish, wildlife and other aquatic life of economic value for locals (Mitsch and Gosselink, 2000). In the coastal and deltaic plains of Pakistan, more than 100 wetlands exist and among them 90% fall on the left side. However, the left side is older than the other, and 6 out of 19 declared Ramsar wetlands of the country also lie on that side (SIDA, 2013; Rahman, 1960). The largest natural lake in Pakistan, namely Manchar lake and a protected game sanctuary as well as Ramser site, namely Haleji lake exists on the right side. In a comparative study on floral species assessment of both sides, Khatoon and Akbar (2008) found that biodiversity on the right side was greater than the other side.

The Indus River presently drains into the Khobar Creek, which is connected with the Arabian Sea. A study by Tabrez et al. (2013) revealed that suspended sediment load at the Kotri barrage (locating about 250 km upstream from the river mouth) during peak flows in 2003 was 65–92 ppm (parts per million) while at the Khobar Creek mouth, where sediment of fluvial and oceanic origin interact, was about 500 ppm. A study by Saleem et al. (2014) determined that suspended sediment concentration in the Hajamro Creek during the northeast monsoon period of 2013 on the right side was 40–100 ppm in a complete tidal cycle while National Institute of Oceanography, Pakistan (National Institute of Oceanography, 1995) reported that in the Shah Samando Creek on the left side it was about 1298 ppm in 1994. The physical characteristics of the soil on the right side were ranging from silt to sand while on the other side was ranging from clay to silt, predominantly (Tabrez et al., 2013). Thus, a distinct difference in the landscape, suspended sediment load and ecological features on the both sides of the Indus Delta motivated us to analyze and compare the eco-geomorphological evolution of the right and left sides over the same timeline.

Various methods, such as field surveys, mathematical modeling, and remote sensing techniques have been used by researchers for revealing the underlying processes and their subsequent impacts over coastal sedimentary systems. However, remote sensing, especially the application of satellite images and retrieval of geospatial information has become an indispensable source of monitoring the coastal systems because it has fewer constraints of financial and human resources (Richards and Jia, 2006; Gade et al., 2014; Harrison et al., 2017; Liu and Mason, 2016).

The literature review shows that most of the research results are limited to the assessment of morphologic degradation on reach- or basin-scale and on temporal scale from short to long timelines but the present study aimed to 1) examine the evolution of tidal creeks network in the Indus Delta, Pakistan, and 2) investigate the potential causes of differential morphologic response of either side of the delta. A large number of geomorphologic parameters along with adequate field observations have been analyzed for determination of more vulnerable creeks and understanding the potential reasons for their anomalous evolution. This evidence-based assessment would help the coastal managers and ecologists for interpretation of land degradation from multi sensor digital imageries and strengthen the integrated coastal zone management (ICZM) plans against the looming threat of climate change and sea level rise.

2. Methodology

2.1. Study area

Sindh coast, one of the most significant offshore areas of the northern Indian Ocean, starts from Karachi and spans up to the Sir Creek near the international border of Pakistan and India (Fig. 1). It looks like an arc shape which is the basically the lower boundary of the fan-shaped Indus Delta. Makran coast of Pakistan in the northwest and Gujrat coast of India in the Southeast also share their boundaries with this coast. After flow regulations and river training works along the main Indus River, the mouths of the creeks were predominantly exposed to oceanic activities that is why the quality and quantity of the adjoining lands are deteriorating perpetually. Fourteen major creeks and many other minor creeks form a naturally carved dendritic network of waterways in the tidal flats (Fig. 1) of the Indus Delta.

This creeks network stretches about 180 km along the Sindh coast and on average it extends longitudinally up to 32 km landward. Physiographically, the tidal flats are composed of tidal cover plain with coarse-textured sediments and gradation approaches to finer sediments landward (WAPDA, 1966). Semi-diurnal to mix types of tides with tidal range 3.5–5.0 m intrude into the creeks (Waheed-uz-Zaman and Saif, 2014).

2.2. Dataset

The dataset used in this study along with software packages used for processing, extraction of required information and its presentation are described in Table 1. The software packages protected under license were acquired from Geographical Information System (GIS) section of the U. S. -Pakistan Centers for Advanced Studies in Water (http://water.muet.edu.pk/), Pakistan and all of the data was graciously shared by the respective agency free of cost, which is duly acknowledged in the forthcoming sections. The width of any water channel, i.e. river or creek is more sensitive to the prevailing stage of water at the acquisition time of aerial or satellite images in a planimetric analysis. Although, identical tidal levels and image acquisition time of any satellite coincide rarely. Therefore, utmost care was taken while the selection of the satellite images used in this study. It was considered to undertake the analysis on similar upstream (river) and downstream (tidal) conditions so that