Article

Spatial and Temporal Variability of Open-Ocean Barrier Islands along the Indus Delta Region

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Abstract: Barrier islands (BIs) have been designated as the first line of defense for coastal human assets against rising sea level. Global mean sea level may rise from 0.21 to 0.83 m by the end of 21st century as predicted by the Intergovernmental Panel on Climate Change (IPCC). Although the Indus Delta covers an area of 41,440 km^2 surrounded by a chain of BIs, this may result in an encroachment area of 3750 km^2 in Indus Delta with each 1 m rise of sea level. This study has used a long-term (1976 to 2017) satellite data record to study the development, movement and dynamics of BIs located along the Indus Delta. For this purpose, imagery from Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager (OLI) sensors was used. From all these sensors, the Near Infrared (NIR) band (0.7–0.9 μm) was used for the delineation and extraction of the boundaries of 18 BIs. It was found that the area and magnitude of these BIs is so dynamic, and their movement is so great that changes in their positions and land areas have continuously been changing. Among these BIs, 38% were found to be vulnerable to oceanic factors, 37% were found to be partially vulnerable, 17% remained partially sustainable, and only 8% of these BIs sustained against the ocean controlling factors. The dramatic gain and loss in area of BIs is due to variant sediment budget transportation through number of floods in the Indus Delta and sea-level rise. Coastal protection and management along the Indus Delta should be adopted to defend against the erosive action of the ocean.

Keywords: satellite remote sensing; Landsat; coastline; barrier island; morphological change; coastal ocean

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Text 1. Radiometric Correction

Radiometric correction is an essential and key pre-processing step for creating higher-level data products from satellite images. The purpose of radiometric correction is to convert the raw counts collected by different sensors (with different radiometric resolutions) to a standard radiometric scale for direct comparisons [49]. The ultimate objective of this study was to use the surface reflectance for the temporal morphological change detection in the barrier islands, therefore, it was necessary to use the surface reflectance product (Level-2) for each sensor. Such product of surface reflectance is only available from Landsat-5 Thematic Mapper (TM), Landsat-7 Enhanced Thematic Mapper Plus (ETM+) and Landsat-8 Operational Land Imager (OLI) sensors, therefore, surface reflectance for Landsat-2 Multispectral Scanner (MSS) image was estimated in-house. As a prerequisite for the estimation of surface reflectance for MSS scene, the radiometric calibration was carried out using the radiometric rescaling coefficients provided in the product metadata file (.MTL file) using Eqs. (1-3) [49].

$$L_\lambda = (G_{rescale\lambda} \times Q_{cal\lambda}) + B_{rescale\lambda} \tag{1}$$

where

$$G_{rescale\lambda} = \frac{L_{max\lambda} - L_{min\lambda}}{Q_{calmax} - Q_{calmin}} \tag{2}$$

$$B_{rescale\lambda} = L_{min\lambda} - \left(\frac{L_{max\lambda} - L_{min\lambda}}{Q_{calmax} - Q_{calmin}}\right) \times Q_{calmin} \tag{3}$$

and

L_λ = Radiance at the sensor's aperture (TOA radiance) for band λ [W/m^2 sr μm]
$Q_{cal\lambda}$ = Quantized and calibrated pixel value for band λ [DN].
Q_{calmin} = Minimum quantized calibrated pixel value corresponding to Lminλ [DN].
Q_{calmax} = Maximum quantized calibrated pixel value corresponding to Lmaxλ [DN].
$L_{min\lambda}$ = Spectral at-sensor radiance, scaled to Qcalmin for band λ [W/ (m^2 sr μm)].
$L_{max\lambda}$ = Spectral at-sensor radiance, scaled to Qcalmax for band λ [W/ (m^2 sr μm)].
$G_{rescale\lambda}$ = Band-specific rescaling gain factor [(W/ (m^2 sr μm))/DN]
$B_{rescale\lambda}$ = Band-specific rescaling bias factor [W/ (m^2 sr μm)]

Text 2. Atmospheric Correction

Atmospheric correction is the process of removing atmospheric artifacts which are introduced during image acquisition by the atmospheric perturbations. Landsat series of satellites for being the longest data record of earth (since 1972), is enabling the users to carry out historical study of land surface changes [51]. Therefore, to take away the burden of data processing from the user community and facilitate uptake of the data by modelers and operational users a surface reflectance product was developed by National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) and the University of Maryland in 2006 [55] for Landsat TM and ETM+ sensors. The processing of the data sets to surface reflectance has further been extended for the Landsat-8 OLI sensor.

For Landsat 4–5 (TM) and Landsat-7 (ETM+), the surface reflectance products are generated from specialized software called the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS). The method uses the 6S (Second Simulation of the Satellite Signal in the Solar Spectrum) radiative transfer model to generate surface reflectance for a Landsat scene using global data sets of water vapor, ozone, geopotential height, and elevation, and aerosol optical thickness (AOT) which is extracted from the Landsat image [56]. Landsat 8 surface reflectance data are generated from the Landsat Surface Reflectance Code (LaSRC), which makes use of the coastal aerosol band to perform aerosol inversion tests, uses auxiliary climate data from Moderate Resolution Imaging Spectroradiometer (MODIS) and uses a unique radiative transfer model [57].

In order to be consistent with the TM, ETM+ and OLI sensors, surface reflectance product for MSS sensor was generated in-house using Dark Object Subtraction (DOS) method [58]. The image based DOS method (Equation (4)) was applied for atmospheric correction in which darkest pixel value from each band is subtracted because some objects do not appear as dark as they really are due to atmospheric perturbations [58].

$$\rho = \frac{\pi\, d^2\, (L_\lambda - L_{haze\lambda})}{(Esun_\lambda\, \cos\theta_S)} \tag{4}$$

where
$L_{haze\lambda}$ = Path radiance for band λ [W/m^2 sr μm]
$E_{sun\lambda}$ = Exo-atmospheric solar irradiance for band λ [W/m^2 μm]

d = Earth–Sun distance [astronomical units]
θ_s = Solar zenith angle [degrees]

Mahiny and Turner (2007) [59] reported that there are very few absolute black targets on the Earth's surface, suggesting an assumed 1% minimum reflectance is better than 0%. It is reported that 1% radiance ($L_{1\%}$) of the dark objects (for each band) is better than 0% reflectance because there are very few objects on earth surface which are absolute black [60] was calculated using Equation (5).

$$L_{1\%} = \frac{0.01 \mathrm{Esun}_\lambda \cos\theta}{\pi d^2} \quad (5)$$

$L_{1\%}$ was further subtracted from the path radiance ($L_{haze\lambda}$), and finally, the surface reflectance (ρ) was estimated using Equation (6).

$$\rho = \frac{\pi\, d^2\, (L_\lambda - (L_{haze\lambda} - L_{1\%\lambda}))}{\mathrm{Esun}_\lambda \times \cos\theta} \quad (6)$$

After performing atmospheric correction (surface reflectance estimation), the L2 MSS image was resampled at 30 m spatial resolution (from 60 m) to make them consistent with the other Landsat images acquired through TM, ETM+ and OLI sensors.