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Research paper

Geospatial approach towards enumerative analysis of suspended sediment concentration for Ganges–Brahmaputra Bay

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A R T I C L E I N F O

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A B S T R A C T

This study presents an easy, modular, user-friendly, and flexible software package for processing of Landsat 7 ETM and Landsat 8 OLI-TIRS data for estimating suspended particulate matter concentrations in the coastal waters. This package includes 1) algorithm developed using freely downloadable SCILAB package, 2) ERDAS Models for iterative processing of Landsat images and 3) ArcMAP tool for plotting and map making. Utilizing SCILAB package, a module is written for geometric corrections, radiometric corrections and obtaining normalized water-leaving reflectance by incorporating Landsat 8 OLI-TIRS and Landsat 7 ETM+ data. Using ERDAS models, a sequence of modules are developed for iterative processing of Landsat images and estimating suspended particulate matter concentrations. Processed images are used for preparing suspended sediment concentration maps. The applicability of this software package is demonstrated by estimating and plotting seasonal suspended sediment concentration maps off the Bengal delta. The software is flexible enough to accommodate other remotely sensed data like Ocean Color monitor (OCM) data, Indian Remote Sensing data (IRS), MODIS data etc. by replacing a few parameters in the algorithm, for estimating suspended sediment concentration in coastal waters.

1. Introduction

Estimating suspended particulate matter concentrations (SPM) over long coastal areas using customary way of in-situ sampling is a lengthy, costly, and laborious process. In contrast, remotely detected spectral radiant energy estimated by satellite sensors can deliver a different, synoptic, rapid, and economical approach for assessing the SPCs in coastal water bodies, lakes, and rivers (Mckim et al., 1984; Curran and Wilkinson, 1985). However, effective algorithms are essential for converting radiance or reflectance values into measurement of water constituents. In sediment-dominated coastal waters, sophisticated algorithms are mainly needed to estimate accurately the suspended particulate concentrations from remotely sensed ocean color data (Robinson et al., 1998; Moore et al., 1999).

Suspended sediment transport is a continuous process occurring in coastal waters. Many researchers have endeavored to estimate the SPMCs in the coastal waters based on the remote sensing reflectance, absorption, and scattered light by water (Tassan and Strum, 1986; Tassan, 1994; Green and Sosik, 2004; Pradhan et al., 2005; Wang et al., 2010; Chauhan et al., 2011; Avinash et al., 2012). Earlier studies about the relationship between SPC and reflectance values in coastal waters suggest that algorithms derived from single band reflectance values may be adopted, where the SPMs increase with increasing reflectance (Curran et al., 1987; Novo et al., 1989).

Later, studies associating the reflectance and water leaving radiance values for different bands were carried out. The single band algorithms have been understood to be the easiest and best possible way e.g., Landsat OLI-TIRS band 4, Landsat TM band 3 or MODIS band 1 (Nellis et al., 1998; Islam et al., 2001; Miller and McKee, 2004; Shi and Wang, 2009). Reflectance in the green and NIR regions has also been proposed e.g. Landsat ETM+ Band 2 (Ouillon et al., 2004) and Band 4 (Ritchie et al., 1990)], but it appears that they are less used. The red band of the visible portion of the spectrum is very sensitive to SPC variations (Schiebe et al., 1992) and is usually used. But the portions of the near-infrared spectrum are also sensitive to SPM thus a combination of several visible and near-infrared bands often produce the strongest SPC-reflectance relationships (Stumpf and Pennock, 1989; Kaliraj et al. (2014)). Marine reflectance in a red channel alone can be reliably used to retrieve SPM concentrations (Nechad et al., 2011; Vanhellemont et al., 2013). However, near infrared reflectance in combination with red reflectance (Xia, 1993; Ruhl et al., 2001; Wang et al., 2009) is being used commonly.

Calculating and mapping of Suspended Particulate Matter

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concentration (SPM), has been routinely done using data from committed wide-swath ocean color instruments such as Orbview-2/SeaWiFS, Aqua/MODIS and ENVISAT/MERIS (Gohin, 2011; Nechad et al., 2010; Ouillon et al., 2008; Van der Woerd and Pasterkamp, 2004) as well as freely accessible Landsat ETM and OLI-TIRS (Qu, 2014; Kaliraj et al., 2014; Cai et al., 2015).

In general, the optical properties of water–sediment mixtures are highly variable, and many factors such as suspended particle size, shape, and color can affect the water–sediment optics (Baker and Lavelle, 1984; Curran and Novo, 1988; Stumpf and Pennock, 1989; Sydor and Arnone, 1997, Rai and Arunkumar, 2015). Due to these optical complexities, it is difficult to propose a universal algorithm for estimating SPMs. Further, various other parameters such as coastal geomorphology, river input, and local coastal circulation influence the SPMs. Against this background, we endeavored to develop a flexible algorithm for estimation of SPMs using Landsat 8 OLI-TIRS and Landsat 7 ETM+ satellite data by improvising algorithms wherever necessary and required. Specific objectives are as follows:

– Preparation of Algorithm using SCILAB package.
– Development of ERDAS Models for processing of remotely sensed images.
– Compilation and preparation of SSC maps using ArcMAP software.
– Demonstration of the usage of above software package for estimating suspended sediment concentration off Bengal delta.

1.1. Theoretical background

Atmospheric correction refers to the process of eliminating the contributions by surface glint and atmospheric scattering from the estimated total reflectance to determine the water-leaving reflectance. The total atmospheric reflectance is the sum of the molecular reflectance, called Rayleigh's reflectance, aerosol reflectance, the coupling term, which takes into account the interaction between molecules and aerosols, specular reflection of the sun (ignored as the sun zenith angle is much larger than the viewing zenith angle), reflectance of foam and whitecaps and can be estimated from wind speed using an empirical relationship (again this reflectance ignored as it is largely corrected during the aerosol correction) (Gordon and Wang, 1994). Marine reflectance also known as water-leaving reflectance, defined as the ratio upwelling radiance just above the water-surface divided by the solar downwelling irradiance.

In NIR band, water is highly absorbing, thus, water-leaving radiance is negligible and can be eliminated, allowing direct estimation of aerosol radiance. The near-infrared and red spectral

Table 1
Glossary of variables and their description.

Variables	Description	Units
ρ_{TOA}	*Top of Atmosphere Planetary Reflectance*	Unitless
ρ_r	*Reflectance due to Rayleigh Scattering by air molecules*	Unitless
ρ_a	*Reflectance due to scattering by Aerosol*	Unitless
ρ_{ra}	*Rayleigh and Aerosol interation Reflectance*	Unitless
ρ_g	*Specular reflectance(glint)of the sun*	Unitless
t_0	*Sun − Sea diffuse transmittance*	Unitless
t_v	*Sea − Sensor diffuse transmittance*	Unitless
ρ_w	*Marine Reflectance*	Unitless
ρ_{wc}	*Reflectance due to foam and white caps*	Unitless
ρ_λ	*TOA planetary Reflectance without solar angle correction*	Unitless
M_ρ	*Band multiplicative rescaling factor*	Unitless
Q_{cal}	*Quantized and calibrated standard product pixel values(DN)*	Unitless
A_ρ	*Band specific additive rescaling factor*	Unitless
θ_{SE}	*Local Sun Elevation Angle*	Degrees
θ_0	*Local Solar Zenith Angle(90 − Sun Elevation Angle)*	Degrees
L_λ	*Spectral Radiance at the sensor's aperture*	$W/(m^2*sr*\mu m)$
Q_{cal}^{MAX}	*Maximum quantized calibrated pixel value*	Unitless
Q_{cal}^{MIN}	*Minimum quantized calibrated pixel value*	Unitless
L_{max}	*Spectral radiance scaled to* Q_{cal}^{MAX}	$W/(m^2*sr*\mu m)$
$L_{\min}$	*Spectral radiance scaled to* Q_{cal}^{MIN}	$W/(m^2*sr*\mu m)$
ρ	*planetary reflectance*	Unitless
d	*Earth − sun distance*	au
F_0	*Mean solar exo-atmospheric irradiances*	$W/(m^2*\mu m)$
τ_r	*Band averaged Rayleigh optical thickness for a standard atmosphere*	Unitless
τ_{oz}	*Band averagedOzone optical thickness for a standard atmosphere*	Unitless
θ_v	*Viewing Zenith Angle*	Degrees
φ_0	*Sun Azimuth angle*	Degrees
φ_v	*Sensor Azimuth angle*	Degrees
$P_r(\vartheta)$	*Rayleigh scattering phase function for scattering angle* ϑ	Degrees
$P_r(\theta_+)$	*For upward radiance*	Degrees
$P_r(\theta_-)$	*For downward radiance*	Degrees
θ_t	*Angle of transmittance*	Degrees
n_w	*Refractive index of water w. r. t air*, 1.34	Unitless
γ	*Ratio of diffused atmospheric transmittances in the two bands*	Unitless
α	*Ratio of marine reflectance in the two bands*	Unitless