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INVERSION MODEL TO DERIVE SHALLOW WATER DEPTH OVER PIROTAN REEF, GULF OF KACHCHH REGION, INDIA

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ABSTRACT

Remote sensing technology has ability to monitor bio-optical properties of ocean water surrounding the reef. Coral reefs are usually found in relatively shallow and clear waters surrounding the continents and island. The objective of this study to derive shallow water depth in coral reef environment over Pirotan reef, Gulf of Kachchh region using hyperspectral imagery. Hyperspectral sensor is one of the best options to study the coral reef environment. A semi-analyticalmethodutilizeshyperspectral remote sensing data to retrieve water depth. Semi-analytical method are the most recent developing methods in shallow water remote sensing. The image of derived water depth has found ranging from 0.1 to 5.0 m. The spatial variation of model water depth has been found different over the reef because of their uneven morphological structure. The water model output of water depth is compared closely with data acquired during field survey over the reef and the root mean square (rms) error was calculated. The correlation coefficient values has been observed around 0.86.

Keywords: Inversion Model, Shallow water depth, Pirotan Reef, Gulf of Kachchh Region.

INTRODUCTION

Remote sensing technology has been developed since last four decades for monitoring coral reef from simple range reef environment to complex reef environment. Remote sensing methods to obtain coral reef ecosystems data are the most effective approach which allow for synoptic coverage and monitoring of large regions, including inaccessible areas (Mumby *et al.,* 1999).Imaging data can differentiate by the dimensions of the remote sensing sensors. Such sensors dimensions control the type and to extract detailed information from an image.

Many coral reef studies belong to the category of shallow water coral reef remote sensing. Optical sensors can penetrate in clear waters to approximately 15 to 30 meters water depth (Mumby *et al.,* 2004). Although, penetration of light is dependent on wavelength and degree of penetration depends upon optical properties of water. Predominantly, the water column scatters the short wavelength radiation of the light spectrum (up to about 450 nm) and absorbs most of the light above 600 nm (Woźniak*et al.,* 2010; Lee *et al.,* 1999). The clearest water depth up to 1 to 2 metre absorbs all the Near Infrared (NIR) radiations and this part of the radiation spectrum is not suitable for remote sensing purpose.

The visibility in water depth provides challenges and opportunities to remote sensing studies of shallow waters coral reef. In order to define remote sensing characteristics of coral reef, it is essential to understand the physics of electromagnetic radiations interactions with the atmosphere, air-sea interface, water column and coral reef substrate types. Different sensors mounted on different platforms records the amount of radiation at various wavelengths reflected from the different objects in water column. The radiance measured by sensors originate from sunlight that travel through the atmosphere is absorbed, reflected and scattered by constituents in the water column

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and then it is transmitted back through the atmosphere to the different sensors at different platforms (http:// www2.dmu.dk/ resc-oman/project/ Backgrounds/ challenges.htm). The total radiance reached at different sensor is mostly comprised of the atmospheric signal and the removal of this signal is a key step for the retrieval of optical properties of water (Gorden, 1997). Water vapour is the main absorbing gas in the atmosphere and the other atmospheric gas followed by ozone, dioxygen and nitrogen (CEOS, 2018). The amount of the absorption and scattering depends on the gas concentration. Air molecules also attenuate the light energy along the path by scattering.

As light travels into the water column, it interacts with different water particles and sediment, which cause the incident light to be transformed by absorption and scattering. The processes of absorption and scattering by optically active constituents present in the water column affect the radiance spectrum and the distribution of the light emerging from the water called water leaving radiance. The water column to which sunlight penetrates depends on both the wavelength of light and the composition of water constituents through which it travels. In highly turbid waters, the satellite signal may be representative of only the upper few centimetres of the water column while in clearer waters signal may be representative of only up to tens of meters depth. In shallow water, sunlight penetrate to the bottom substrate and reflected back to the surface making bottom reflectance, an additional contributor to the water leaving radiance. In such shallow waters, different bottom substrate types, water depth may be estimated (Lee *et al.*, 2007; Leiper *et al.*, 2014).

Many optical models have been developed for the subsurface irradiance reflectance but satellites sensors measure the water leaving radiance. The absorption and scattering characteristics of water and its constituents are described as the inherent optical properties (IOPs) (Thomas and Stamnes, 1999). The spectral quantity and quality of water leaving radiance is mostly determined by the IOPs. An optical property is inherent if it is independent of the ambient light field within that medium and depends only upon the medium (Mobley, 1994).

The most important IOP's are the spectral absorption coefficient $a(\lambda, z)$ the scattering coefficient $b(\lambda, z)$ and the beam attenuation coefficient $(\lambda, z) = a(\lambda, z) + b(\lambda, z)$, where λ is the wavelength of light and z is the water depth. As IOP's are directly linked to the water constituent and their value are used to determine the subsurface light intensity, type of water, solar heat flux with depth, pigment concentration, turbidity and sediment loading (Lee *et al*., 2002).

Study Area

Pirotan reef lies between 22°34' N and 22°38' N Latitudes and 69°55' E and 69°59' E Longitudes within the Gulf of Kachchh region and covers a total area of 12.9 km2 (Figure 3.7). It is northernmost fringing reef in protected zone of Gulf of Kachchh Marine National Park and Sanctuary. This site was selected as a test site

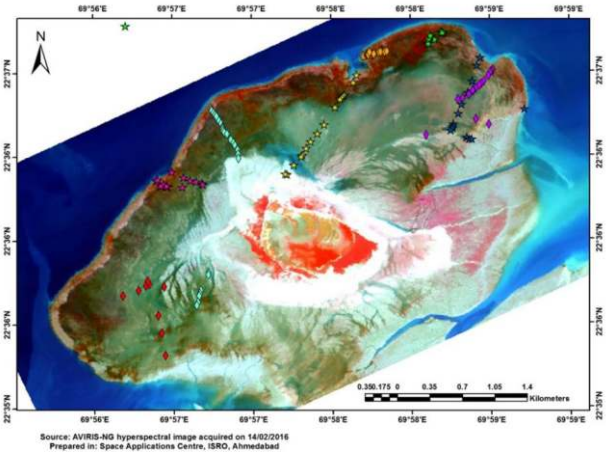

Figure-1. Study area ofRGB airborne hyperspectral imagery of Pirotan reef where *in-situ* data were collected during two survey periods: February 2016 (marked by star with different colours) and February 2018 (marked by diamond with different colours).

because it was open for tourist. Airborne remote sensing is the most common platform which is used to collect low-altitude image. Gulf of Kachchh region is very rich in terms of biodiversity value and supports varied coastal habitats including coral reefs, mangroves, creeks, mud flats, islands, rocky shores, sandy beaches, etc. (Arora *et al*., 2018) and mostly consisting of dead coral boulders and rubbles. Gujarat coast of India is a macro-tidal environment marked with semi-diurnal tidal desiccations (Navalgund *et al*., 2010). The mean spring tidal influx spread from the mouth to the closed end of the Gulf of Kachchh and it lies in the range of 2.1 m to 6.2 m.

MATERIALS AND METHODOLOGY

The objective of this study is to provide a preliminary assessment of *in situ* and shallow water remote sensing studies of coral reef environment. AVIRIS-NG hyperspectral data can solve the problem of water depth based on spectral reflectance of substrate types. A physics-based approach has chosen to derive water depth from hyperspectral imagery. This method can allow reduction in the amount and frequency of *in situ* data. AVIRIS-NG instrument has been used for acquiring hyperspectral imagery data over Pirotan reef, Gulf of Kachchh region during low tide conditions (Figure-1). Data acquisition time was optimised at low tide period to get the maximum exposure of the reef above msl (mean sea level). Hyperspectral imaging data over Pirotan reef was taken from Beechcraft B-200 aircraft with high spatial resolution (7.8 m) and spectral resolution (5 nm) on 14 February 2016 at 07:05:14 hrs GMT (12:35:14 hrs IST). Hyperspectral imaging data was collected from an altitude of ~8 km. Low winds, high visibility and clear skies were observed during the Ground truth campaign organized synchronously with imaging time. The main limitations to study shallow water depth over coral reef environment are lack of light penetrations in shallow water. An inversion method of a semi-analytical model is utilized to retrieve water depth.

The reflectance measured by an airborne hyperspectral sensor from above the water surface in shallow coral reef environment is mainly controlled by absorption coefficient, backscattering coefficient, water depth and the bottom albedo. It is also influenced by Raman emission, fluorescence, the sun angle and output radiance (Marshall and Smith, 1990; Morel and Gentili, 1993; Lee et al., 1994).

$$R_{rs}=f(a(\lambda),b_b(\lambda),\rho(\lambda),H,\theta\_w,\theta\_v,\phi) \quad (1)$$

Where $\alpha(\lambda)$ is the absorption, $b_b(\lambda)$ is the backscattering, $\rho(\lambda)$ is the albedo, H is the depth, θ_ω is the subsurface solar zenith angle, θ_ω is the subsurface viewing angle from nadir, and ϕ is the viewing azimuth angle from the solar plane.

The water AOPs such as $\alpha(\lambda)$, $b_b(\lambda)$ are the main physical parameters leading the magnitude and spectral composition of the backs cattered radiation from the water surface (Maritorena *et al*., 1994; Mishra *et al*., 2007).

RESULTS AND DISCUSSION

The physical, biological and chemical properties of the waters in Gulf of Kachchh region are influenced by the presence of the tidal effect and climate change. The largest causes of water quality degradation originate from anthropogenic activities. Remote sensing data provides spatial information of changes in shallow water depth. Inversion models utilize hyperspectral remote sensing datataken over shallow water coral reef environment in Pirotan reef to retrieve water depth. Semi-analytical method or Physics-based method are the most recent developing methods in shallow water remote sensing. A model-driven optimization model has been used to estimate the water depth and model was adapted to run in MATLAB. AVIRIS-NG hyperspectral image was processed in ~ 8 hours and provide more accurate information of water depth. Inversion model output indicated close agreement between model estimated water depth and field measurement of water depth. The spatial variation of model water depth has been found different over the reef because of their uneven morphological structure (Figure-2). The image of derived water depth has found ranging from 0.1 to 5.0 m. The water Model output of water depth is compared closely with data acquired during field survey over the reef and the root mean square (rms) error was calculated (Figure-3). The correlation coefficient values has been observed

around 0.86.A key input to any semi-analytical inversion model is the pure spectral reflectance of bottom seagrass ($P_{seagrass}$) or sand (P_{sand}) to invert the corresponding R_{rs} for a given pixel (Garcia *et al.*, 2018). The pure bottom reflectance of seagrass and sand is chosen based on scene-specific reflectance and reflectance ratio values. Accuracy of water depth retrievals is depending on the pure end member of bottom which is used in the model during the inversion. The use of incorrect bottom reflectance can lead to estimate inaccurate retrievals of water depth. For each pixel in an image, an inversion model run backward to find the best combination of input parameters value to give the closest match between the measured reflectance and the model output (Hedley, 2013). Semi-analytical model derives not only water depth but also others water column parameters like phytoplankton absorption, CDOM absorption, bottom albedo and backscattering due to suspended sediments.

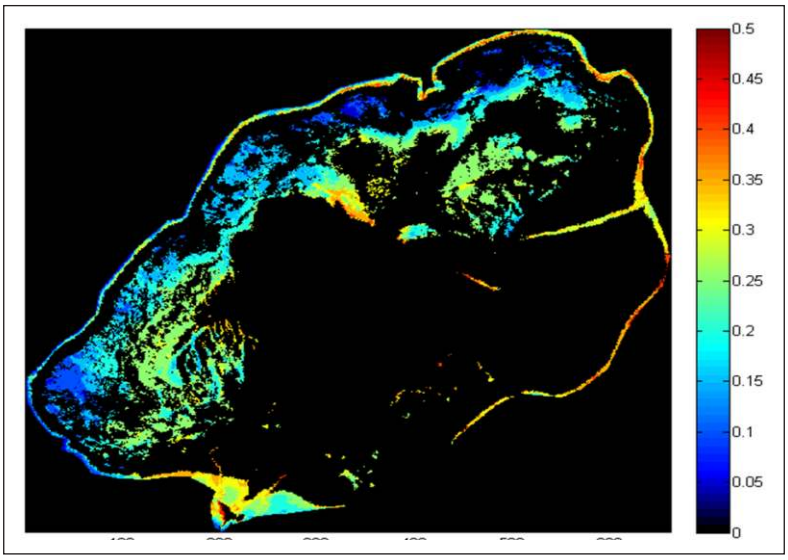

Figure 2: Image of derived water depth (in metres) of Pirotan reef based on the inversion model.

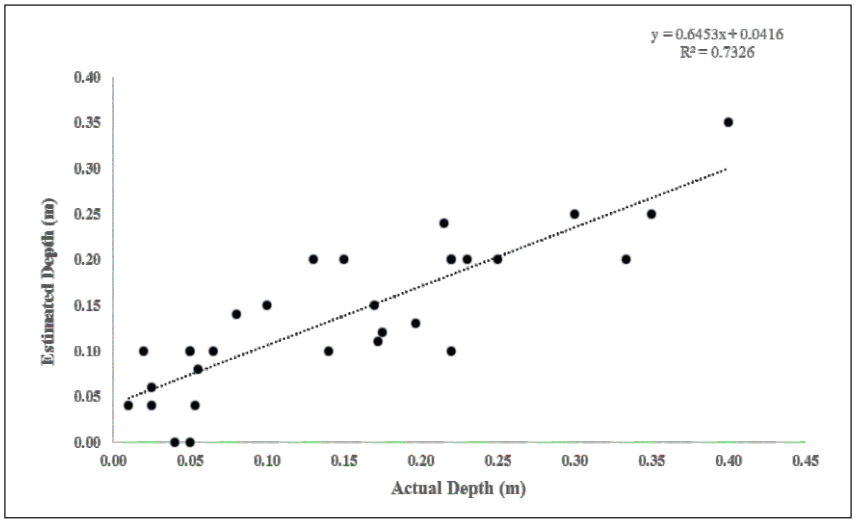

Figure 3. Comparison of model output of water depth with data acquired during field survey.

CONCLUSION

This study employed aninversion model that assess the spatial information of shallow water depth over Pirotan reef with the help of hyperspectral imagery. Airborne hyperspectral remote sensing data has been used a reef-up approach to map water column information. This study achieved by measuring *in situ* pure end-member spectral signatures, processing them to be compatible with AVIRIS-NG image data. Semi-analytical inversion models provide better result than empirical based inversions.

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