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Application of hyperspectral data for Development of spectral library of mangrove species in the Sunderban Delta

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ABSTRACT

Remote sensing has played a crucial role in mapping and understanding of the spatial pattern of mangrove forests and changes in its areal extent caused by natural disasters and anthropogenic forces. So far traditional pixel-based classification of multispectral imagery has been widely applied for broad mapping of mangrove covers. But the recent and more advanced hyperspectral data taken from sensors (like Hyperion) is expected to demonstrate the potential for reliable and detailed characterization of mangrove forests including species level classification. This paper demonstrates the potential of hyperspectral imagery for species level identification of mangroves in the Henry Island of Sunderban Biosphere Reserve, West Bengal. After pre-processing of hyperspectral data, the spectral signature of each species have been extracted from the Hyperion data after which a spectral library has been developed comprising the seven dominant mangrove species of the region namely Excoeocaria Agallocha, Avicennia Officinalis, Ceriops Decandra, Avicennia Marina and Phoenix Paludosa, Brugueira Cylindrica, Aegialitis.

Keywords: Spectral Library, Atmospheric Correction, Geometric Correction, Mangrove species, Hyperspectral

1. Introduction

The ecological importance of mangroves is over exemplified in literature. Living in two worlds at once, mangroves protect offshore ecosystems from terrestrial sediments flowing downstream and protect coastlines from wave energy. They are a unique, yet undervalued and destroyed ecosystem, having had their initial global range reduced to less than 50% due to anthropogenic factors.

Understanding of mangrove vegetation dynamics in a particular area is a pre-requisite to conservation and management directives such as establishment, protection and management of re-afforestation plots in the frame work of regeneration projects. For more than a decade, remote sensing has played a crucial role in mapping and understanding changes in the areal extent and spatial pattern of mangrove forests caused due to natural disasters and anthropogenic forces (Gao, 1999) (Ramsar Convention, 1971). While traditional pixel-based classification of Landsat, SPOT, LISS III, LISS IV and ASTER imagery has been widely applied for mapping mangrove forest (Aschbacher et. al.,1995) (Kanniah et. al.,2005) (Sulong et.al.,2002), more recent types of satellite imagery, the hyperspectral data, taken from sensors like Hyperion is expected to demonstrate the potential for reliable and detailed characterization of mangrove forests including species, leaf area, canopy height, and stand biomass(Demuro and Chisholm, 2003). The application of hyperspectral technology may be a step closer for more accurate tropical mangrove species discrimination.

The potential of hyperspectral imaging and image processing has already been demonstrated for numerous applications in vegetation structure, composition and physiology (Kumar et. al., 2001) (Prasad et. al., 1992). This advantage is mainly driven by its ability to measure reflectance and absorption in specific and narrow spectral bands. Airborne and satellite hyperspectral data offer a large number of narrow, contiguous, spectral bands, covering the 400 to 2,500 nm range of the electromagnetic spectrum. This greatly increases the level of detail, because a characterization of the complete spectra of mangrove cover types is possible. Measurements beyond the non-photosynthetic spectral range facilitate new possibilities to differentiate mangroves based on additional components, such as leaf water content, leaf chemistry in relation to ecosystem, and environmental changes. The ability to detect physiological stress conditions by spectral reflectance and, especially, to support mangrove monitoring and management, is of great value. As a result, hyperspectral data allows for a better separation of feature types based on their unique spectral reflectance and absorption characteristics (Held et. al., 2003). Hyperspectral data may therefore improve our ability to differentiate mangroves at species level (Vaiphasa, 2003) (Vaiphasa, 2004) (Vaiphasa , 2005).

2. Objective

The main objective of this study is to demonstrate the potential of hyperspectral imagery and develop a spectral library of the pure mangrove species identified in the study area in Sunderban.

2.1 Study area

As a case study, the pristine mangrove habitats of Henry island (approximately 10 sq. km. in area, extending between 21°36′00″N to 21°34′00″ N latitude and 86°16′30″ E to 88°18′30″ E longitude) of the Sunderban Biosphere Reserve of West Bengal have been selected for the present study. The selection of the study area is based considering the fact that Sunderban harbours a rich and bio-diverse mangrove community with a wide array of ecologically rare, endangered and endemic mangrove species. Henry Island is that, the seaward edge of the mangrove is dominated by species of Avicennia and Sonneratia. Behind this zone is a zone of mixed mangrove forest species of Rhizophora, Sonneratia, Brugueria, Phoenix, Ceriops and Xylocarpus, Aegialitis and Excoecaria.

3. Methodology

3.1 Remote sensing data acquisition

An EO -1 Hyperion image of the study area was procured from USGS Earth Resources Observation and Science (EROS) Center and cloud free data was acquired on May, 2011 by USGS and subsequently received. Figure 1 shows the Hyperion image of Henry island acquired at a wavelength of 1033 nm.

3.2. Image pre-processing

3.2.1 Atmospheric correction

The 242 bands have been re-sized to 165 after discarding the bands with no information (Han et. al., 2002). The bands with severe water absorption have been retained. The Fast Line of Sight (FLAASH) and Quick Atmospheric Correction (QUAC) algorithms have been run on the images. The scene center location, sensor type, flight date, sensor altitude, average ground elevation of the scene, flight time has been used as input in FLAASH for conversion of radiance values to reflectance values. As the mangrove forests are tropical in nature and experiences a maritime climate, better accuracy has been achieved by choosing a tropical atmospheric model and a maritime aerosol model for correction and the water vapour content information extracted from Hyperion water absorption bands.

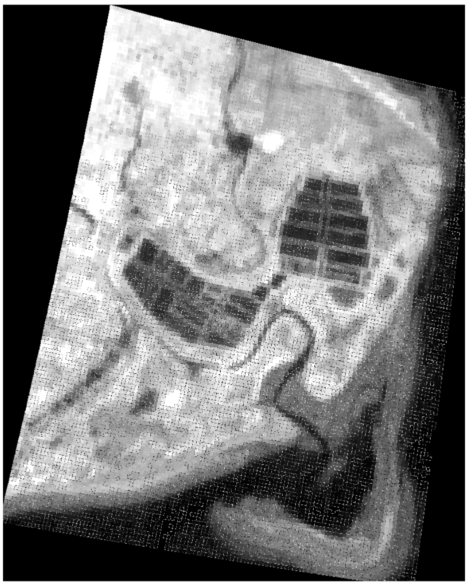

Figure 1: Hyperion image of Henry Island acquired at a wavelength of 1033 nm

3.2.2 Geometric correction

Image to Map method has been used for selecting the Ground Control Points with respect to the topographic sheet of the study area.

3.2.3 Delineation of forested region from clouds and water body

Sub-setting and masking of water bodies, aquaculture, agricultural land, urban area and clouds have been done to ensure exact delineation of the mangrove canopy from the non-mangrove entities which has been filtered out for further processing.

3.2.4 Data Dimensionality reduction without losing information

Minimum Noise Fraction (MNF) and Inverse MNF has been performed on the 165 bands of Hyperion data for removal of redundant data and noise from the atmospherically corrected data.

3.3 Field visit and collection of data / samples (understanding of ecosystem)

Comprehensive field visits of Henry (study area) in Sunderban have been made. A ground survey of the study area (as far as accessible and practically possible) has been made to precisely identify and collect samples of mangrove species along with mapping of geographical coordinates of the study trail. Sample plots with 30m x 30 m spatial resolution that are identical to the resolution of Hyperion image (30 m) were established to estimate the mangrove species fraction on the ground with the aid of the DGPS (Ramsey and Jensen, 1996).

3.4 Creation of spectral signature and spectral library of selected mangrove species

Five pure patches of end members of mangrove species existing in Henry Island have been collected during field survey. The general reflectance pattern of all the species shows a typical healthy vegetation spectral profile. They have low spectral reflectance in visible bands (approximately 400–700 nm) and increase dramatically in the wavelength region between the red and near infrared band, known as “red edge” region (between 680 and 740 nm). The ground control points measured during the field survey has been plotted on the Hyperion image of the study area and the spectral signature of each species have been extracted from the image. Thereafter, a spectral library has been developed comprising the five dominant mangrove species of the region.

4. Results and discussion

There has been a significant enhancement in the spectral profile of mangrove species in the study area after application of the atmospheric correction algorithms. There has been further enhancement of the hyperspectral image followed by reduction of noise and redundant data in the imagery after application of Minimum Noise Fraction algorithm. Figure 2 shows the change in the spectral profile of Avicennia Officinalis before and after correction.

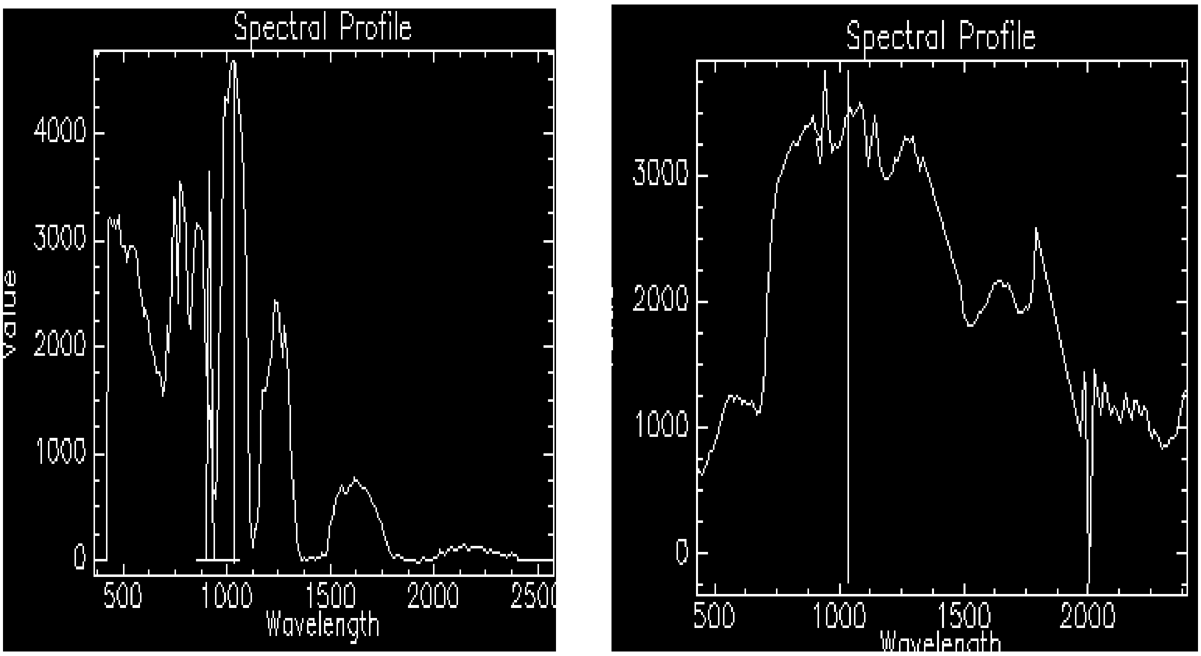

Figure 2: Spectral Profile of Avicennia Officinalis before and after FLAASH Correction

To ensure exact delineation of the mangrove canopy, the non-mangrove entities have been filtered out for further processing. Figure 3 shows the masked image of Henry Island comprising only of the mangrove forested region of the area.

Figure 3: Masked image of mangrove forested area of Henry Island

A ground survey of the study area resulted in precise identification and collection of ground control points of dominant mangrove species. The spectral signature of the individual species have been collected and plotted on the Hyperion image of Hennry Island. Figure 4 is the spectral library of seven dominant mangrove species of Henry Island, Sunderban namely Exocaria Agallocha(orange), Avicennia Officinalis(Blue), Ceriops Decandra(red), Avicennia Marina (green) and Phoenix Paludosa(cyan), Brugueira Cylindrica (magenta), Aegialitis (yellow).

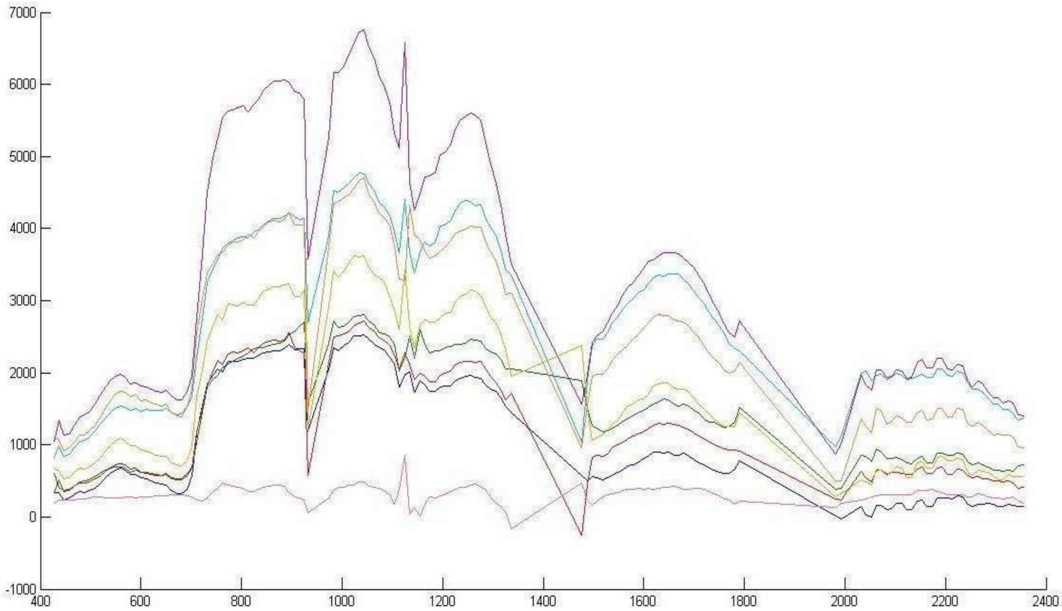

Figure 4: Spectral library of seven dominant mangrove species in Henry Island

The reflectance of Excoecaria Agallocha and Avicennia Officinalis is towards the lower side in the visible region as compared to the other five species throughout the visible region, Near Infra Red (NIR) and Short Wave Infra Red region (SWIR). The highest reflectance is that of Brugueira Cylindrica, Aegialitis and Phoenix owing to its leaf colour and canopy density. The species are quite differentiable in the Near Infra Red region. In this zone, the reflectance is essentially due to the internal structure of the leaf and the radiation that is able to penetrate (Curran, 1989).

In the SWIR region, the species curves are quite distinct. This is the hydric zone where the amount of water inside the leaf affects the pattern of spectral reflectance. It has been observed that the reflectance of mangrove species in this band is lower than non-mangrove vegetation. Low reflectance of mangrove leaves would be attributed to weaker scattering due to smaller amount of intercellular air spaces in mangrove leaves compared to non-mangrove leaves (Elvidge, 1987) (Elvidge, 1990). Low reflectance of mud or water in the SWIR bands may further reduce the reflected radiance of mangrove forests as a whole.

5. Conclusion

Most of the mangrove genera and families are not closely related to each other, but what they do have in common is their highly developed morphological, biological, physiological, and ecological adaptability to extreme environmental conditions. The most important characteristics to achieve this kind of adaptability are pneumatophoric roots (*Avicennia*, *Sonneratia* species), stilt roots (*Rhizophora*, *Brugueria*, *Ceriops* species), salt-excreting leaves, and viviparous water-dispersed propagules. Mangroves build communities parallel to the shoreline. The species composition and structure depend on their physiological tolerances and competitive interactions. Distance from the sea or the estuary bank, frequency and duration of tidal inundation, salinity, and composition of soil are crucial environmental factors. Mangroves exhibit a high degree of ecological stability with regard to their persistence and resilience. However, they are highly sensitive to changes, especially within hydrological environments (e.g., water-quality changes), which go beyond their ecological range of tolerance; thus, the ecosystems act as change indicators on a broader scale.

Hyperspectral imaging offers the possibility of identifying and characterizing individual mangrove species in the Sunderban Biosphere Reserve on the basis of the unique reflectance patterns that result from the interaction of solar energy with the molecular structure of the tree crowns. It has been possible to identify five dominant species in the study area. It is therefore a valuable tool for mapping of mangrove forests in tropical dense virgin forested regions. The spectral library developed so far would help in identification of mangrove species in areas which are not accessible by man. More extensive field visits and advanced image processing techniques will be applied so that more number of species can be identified.

The understanding of mangrove dynamics can be applied to formulation of conservation and management directives (Saxena et. al., 2004), such as establishment, protection and management of afforestation areas in the framework of regeneration and restoration projects (Ecology and Climate Justice, 2009). Accurate and up-to-date information on the nature, extent, structure and distribution of the mangrove ecosystem is an essential requisite for ensuring their sustainable management. The recent devastation caused by the infamous cyclonic storm of "Aila" in the Sunderbans in West Bengal has brought about a significant change in the land cover which has attracted the attention of the researchers and media all over the world. This has necessitated the need for a detailed species level classification and mapping of mangroves that would help to identify the extent of damage to this floral community (Green et. al., 2000). For this reason, any accurate and time saving species identification mechanism is required to be developed that will ultimately ensure the overall developmental strategy of this region.

5.1 Limitations of study

The spectral signatures derived from the satellite imagery may have some limitations, primarily because the spectral signal of these plant communities is strongly influenced by tidal effects on the soils. The spectral signatures are also altered by the physiological status of plants and the morphological properties of each species. Satellite data (average altitude 705 km for Hyperion data) are altered by atmospheric properties, especially in coastal areas where air humidity is usually extremely high. Even after the application of atmospheric correction techniques, the errors cannot be fully removed. Hence the use of field based hyperspectral spectro-radiometers need to be used to compare and correct the errors that may be there in the remotely sensed hyperspectral imagery. Hence, it may be concluded that, as the interface between land and ocean is an extremely dynamic area, the properties of its main components, such as soils and plant communities, vary on both short (diurnal and seasonal) and long time scales (yearly, century etc.). These variations, the daily changes in particular, are major obstacles to an accurate spectral characterization of each component of the intertidal zone.

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