ASSESSMENT OF SUSPENDED SEDIMENT CONCENTRATION IN THE SURFACE WATER USING REMOTE SENSING

Asif Mumtaz Bhatti [1], Seigo Nasu [2] and Masataka Takagi [3]

[1] PhD Student, Department of Infrastructure Systems Engineering, Kochi University of Technology, Tosayamada-cho, Kami-City, Kochi, 782-8502, Japan. asif_engr@yahoo.com

[2, 3] Professor, Department of Infrastructure Systems Engineering, Kochi University of Technology, Kochi, Japan.

ABSTRACT

Remote sensing is an effective tool for the assessment of suspended sediment in surface water. Experiments were conducted in the laboratory to investigate the spectral response of suspended sediments concentration, distribution and settling with time. A hyperspectral Field SpecPro FR Spectroradiometer was used to measure reflectance from the water in the electromagnetic spectrum region of 400 nm to 900 nm. Reflectance of water with varying concentration of clayey red soil ranging from 50 to 1000 mg/l was measured. Significant change in reflectance was observed for the same suspended sediment concentration (SSC) with time. However, the change in reflectance was more in visible domain. This paper analyses the relation between suspended sediment concentration and the reflectance. The near- infrared (NIR) wavelength was found to be optimum range for assessment of suspended sediment concentration in surface water.

Keywords: Remote sensing, Suspended sediment assessment, Optimum range

1 INTRODUCTION

High concentration of suspended sediment in water is a critical element in the economic feasibility of a project and could shorten the useful life of reservoirs & dams. It is estimated that approximately 1,100 km^3 of sediments have been accumulated in the world's reservoirs, taking up almost one fifth of the global reservoir storage capacity [1]. The reservoir resulting from the construction of a dam in a river is a site for the sedimentation of solid particles transported by the river, due to the decrease in the flow transport capacity. On the one hand, this sedimentation process has engineering consequences because it leads to a reduction of the storage capacity of the reservoir [2] and, hence, of its efficiency. It is important to incorporate sediment assessment as an integral part of water resources and environmental planning and management. The reason for success of remote sensing in such surveys is the strong positive relationship that exists between SSC and remotely sensed spectral reflectance.

Variations of sediment type (grain size and refractive index) and changing illumination conditions affect the reflectance signal of coastal waters and limit the accuracy of sediment-concentration estimations from remote-sensing measurements [3]. It is believed that the main differences between the two types of waters are located in the 0.4–0.7 m spectral range [4], where the turbid water has significantly larger reflectance than the clear water. This formed the basis for the detection of turbid water and SSC estimation algorithms. If the range of suspended sediments is between 0 and 50 mg/l, reflectance from almost any wavelength will be significantly related to suspended sediment concentrations [5]. As the range of suspended sediments increases to 200 mg/l or higher, curvilinear relationships have to be developed with reflectance in the longer wavelength. Significant relationships have been shown between suspended sediments and radiance or reflectance from spectral wave bands or combinations of wave bands on satellite sensors. Ritchie et al. [6] using in situ studies concluded that wavelengths between 700 and 800 nm were most useful for determining suspended sediments in surface waters.

Suspended sediments are the most common pollutant both in terms of weight and volume in surface waters of freshwater systems. Suspended sediments may serve as a surrogate contaminant in agricultural watersheds since phosphorus, insecticides, and metals adhere to fine sediment particles. Remote sensing is an effective tool for the assessment of suspended sediment in surface water. Numerous researchers have developed algorithms for the relationship between the concentration of suspended sediments and radiance or reflectance.

A few studies have taken the next step and used these algorithms to estimate suspended sediments for another time or place [7]. The aim of the study was simply to investigate the relationship between suspended sediment concentration (SSC) and reflectance in a column of water. The objective was to understand the change in reflectance with SSC and change in reflectance for the same SSC with time.

2 METHODS

The experiments were performed in Laboratory at Kochi University of Technology. The experiments were carried out in a black painted room to avoid extraneous reflectance. Field SpecPro FR Spectroradiometer (Analytical Devices, Inc., Boulder, CO) was used to collect the upwelling radiance from the water surface. This portable spectrometer combines three spectrometers to cover the wavelength range from 350 to 2500 nm. A photodiode array spectrometer is used to cover the 350 to 1000 nm spectral range (UV/VNIR), while two fast-scanning (0.1 sec) spectrometers provide coverage for the two wavelength ranges from 1001 to 1800 nm and 1801 to 2500 nm (SWIR 1 and SWIR 2). The sampling interval is 1.4 nm. Radiation input to the ASD FieldSpec FR spectrometers is through a fiber optic bundle, 5 meters in length. The fiber optic cable provides the ability to quickly and easily point the spectrometer field of view at different targets, especially when using the pistol grip. The spectroradiometer was calibrated in the laboratory before measuring water surface radiance. The warm up time, sensor height, cable flexure test and illumination angle was measured by making radiance measurements of reference panel in a black room. The reference plaque was a Labsphere white Spectralon of dimensions 12.5cm x 12.5cm.

The clayey red soil samples served as ingredient for sediment loading were collected from the central area of Okinawa Island (coordinates: 26º23´N and 127º73´E). Soil properties are closely related to geological and geomorphological components [8]. The soil sample was air dried and manually sieved to assure uniform grain size. For this study, data from 400 to 900 nm was used because noise was pronounced at wavelength shorter that 400 nm and longer than 900 nm. The sensor was attached to the mechanical arm and positioned over the water at the height of 1 m. Radiance from the water surface with suspended sediments concentration (clayey red soil) ranging from 50 to 1000 mg/l was measured in a black coated water tank. The depth of water column was kept constant at 1 meter. The sediments were kept in suspension by manually stirring at regular intervals. In addition, radiance was measured for the same SSC without stirring after 1,2 and 3 minutes to investigate the effect of SSC distribution on reflectance value.

Reflectance was calculated as a simple ratio between target and reference panel using following equation.

$$\% R(\lambda) = \frac{L(\lambda)}{S(\lambda)} \times Cal(\lambda)$$

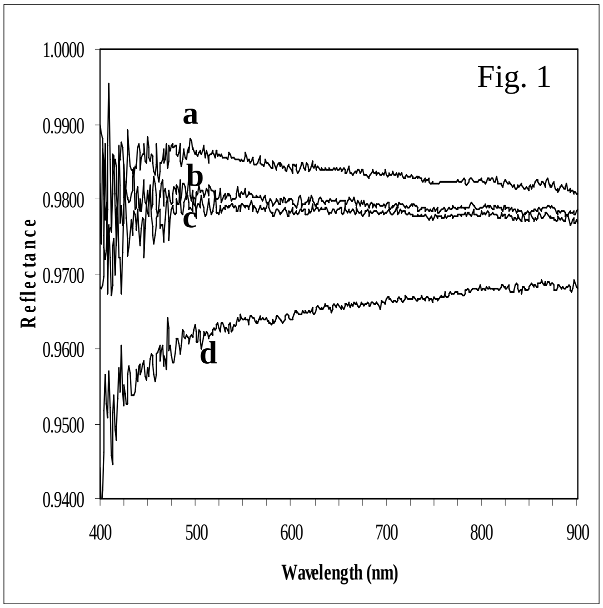
Where $L(\lambda)$ is the radiance measured from the water surface, $S(\lambda)$ is the radiance from the reference panel and Cal (λ) is the calibration factor for the reference panel. Using this method, all parameters that are multiplicative in nature, such as the spectral irradiance of the illumination source and the optical throughput of the field spectrometer, and present in both the spectral response of a reference sample and the target material, are mathematically eliminated.

3. RESULTS AND DISCUSSION

3.1 EQUIPMENT CALIBRATION

The ASD FieldSpec FR spectroradimeter is calibrated in the laboratory to achieve maximum accuracy of radiance measurements. The calibration room was completely darkened, the only source of illumination was the halogen lamp. The instrument's fiber optic probe is placed in a stationary position at a 45 degree angle to the Spectralon panel. The collection of accurate spectra requires an awareness of the influences of the various sources owing to sensitivity of the instrument. Instrument warm up time, field of view, illumination geometry, sensor height above the water surface and target characteristics must be considered for accurate measurements. The experimental design must be modified to account for the characteristics of the available instrumentation. Experiment was performed by making radiance measurement of reference panel with different warm up time.

Sensitivity of spectroradiometer changes with temperature, and this is particularly significant when it is warming up. The measurements were made during instrument warm-up, after the spectrometer was turned on.



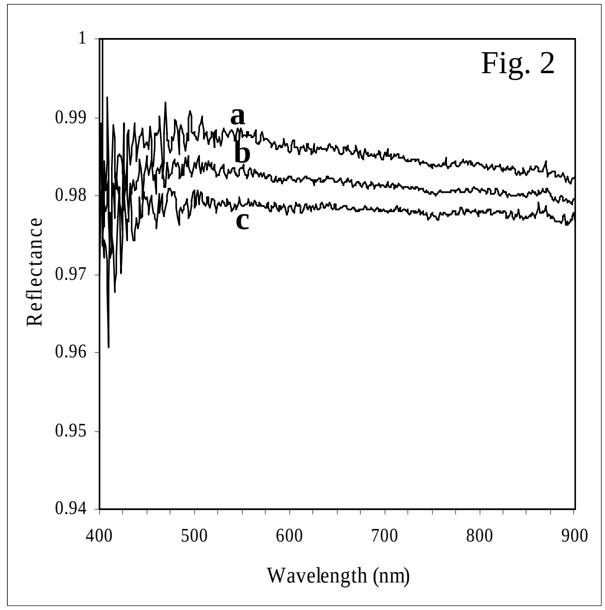
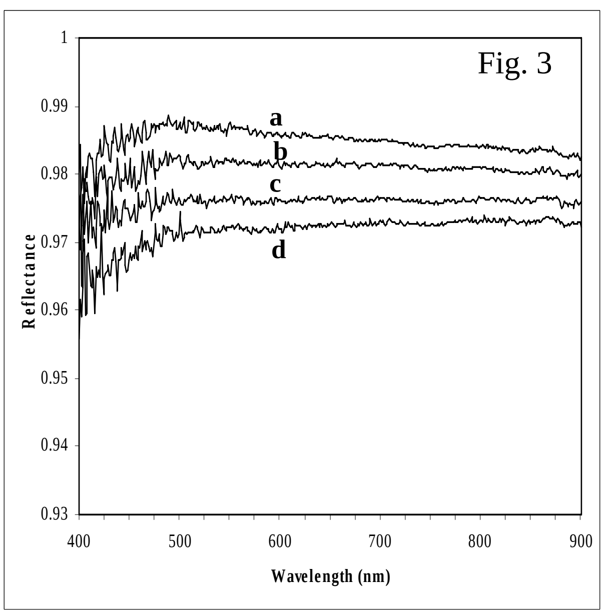


Figure 1. Reflectance measurement of reference panel with different warm up time after the spectroradiometer was turned on, a: After 90 minute b: After 120 minute c: After 150 minute d: After 10 minute

Figure 2. Reflectance measurement of reference Panel with different sensor height above the water surface, a: 1.2 meter above the water surface b: 0.5 meter above the water surface c: 1 meter above the water surface



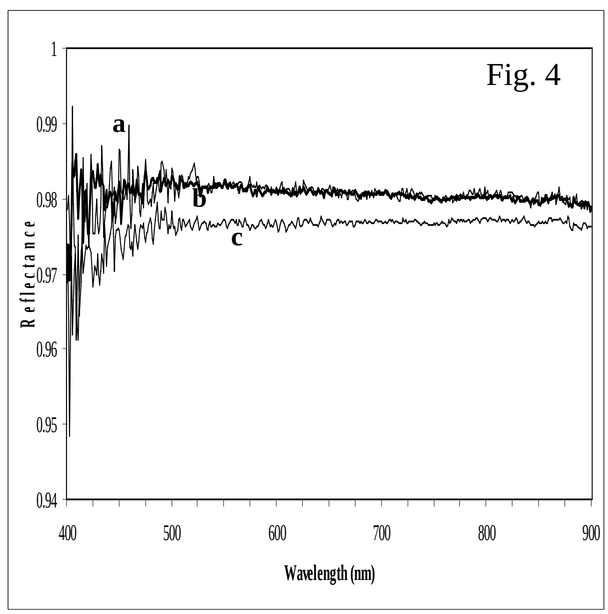


Figure 3. Reflectance measurement of reference panel with different cable positions, a: one twist in cable b: zigzag cable c: Straight cable d: many twist

Figure 4. Reflectance measurement of reference panel with different illumination angle; a: 60 degree b: 30 degree c: 45 degree

The warm up time of 150 minutes was selected and kept for all experiments (fig.1). Also, radiance measurement was taken with different sensor height above the water surface, different illumination angle with constant distance between the reference panel and the light source and different cable placements. Flexure of the cable effect the radiance measurement of the target by changing the signal level. Sensor height of 1 meter above the water surface was selected for all experiments (fig. 2), with straight fiber cable position (fig. 3), and illumination angle of 30 degree (fig. 4) was kept during radiance measurement of water surface with varying suspended sediment concentration (SSC).

3.2 SUSPENDED SEDIMENT REFLECTANCE

The reflectance spectra were computed for suspended sediment concentration ranging from 50mg/l to 1000 mg/l. The spectral shape is almost similar, however, the magnitude of reflectance increased with increase in SSC as depicted in figure 5. It is noted that reflectance value increased at all wavelengths above 500 nm with the increase in SSC. However from 700 to 900 the reflectance increased systematically with increase in SSC. A strong correlation exists between SSC and reflectance in the red and NIR region. In the present research work the bottom effect was not considered owing to already done research work. At a depth of 80 cm, the bright bottom signal is virtually non-existent when suspended sediment concentrations were above 100mg/l. At wavelengths between 740 and 900nm, bottom brightness has no impact due to the absorption of near-infrared energy by water [9].

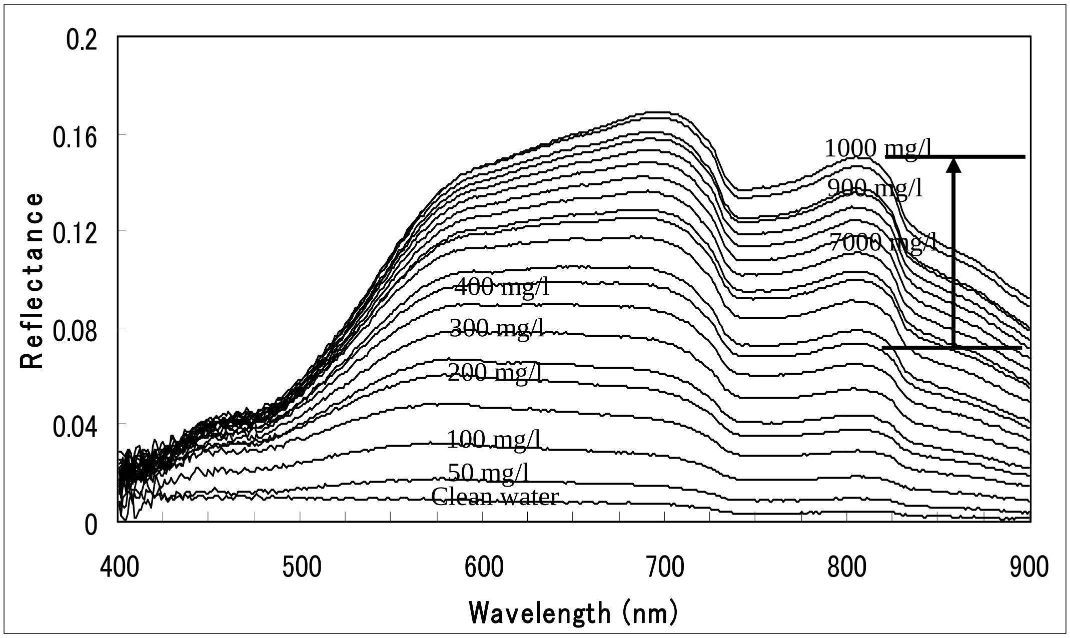


Figure 5: Spectral reflectance of water with varying concentration of clayey red soil

The low reflectance value is due to the black coated inner walls of the tank, which absorb much of the incident light. Maximum reflectance is observed in the visible domain from about 550 to 700 nm followed by the second peak at 750 to 850 nm. High absorption is observed beyond 750nm in the near infra-red region. Increases in suspended sediment load lead to a shift in the reflectance spectral profile upwards. The results agreed with work done by the numerous researchers.

3.3 DISTRIBUTION OF SUSPENDED SEDIMENTS WITH DEPTH

Assessment of suspended sediment in water bodies is based mainly on assumption of uniform distribution of suspended sediments along the depth. Most of the sediment which is eroded from the land surface is in the form of fine particles which are transported in water courses as a suspended load. These fine sediments account for the turbidity often observed in rivers and their natural fall velocity in water is as low that the natural turbulence maintains them in suspension. A small proportion of the sediment, perhaps around 10%, is courser material which is transported as bed load. These sediments roll along the bed of the river or saltate (hop) close to the bed. Reservoirs act as settling basins for both types of sediment [10]. However, the distribution of sediments is not uniform and varies with depth depending on sediment characteristics, precipitation, run-off, temperature, water flow, and wind speed. Specular reflection from a wind-roughened water surface constitutes a serious problem in the interpretation of spectral data [11].

The objective to perform the experiment was to investigate the effect of non-uniform distribution of suspended sediment on remotely sensed data. Sediments were mixed in water uniformly by manually stirring the water sample for a few minutes. Spectral reflectance of water is measured for the constant amount of sediments immediately after the mixing of sediments. Also for the same concentration of suspended sediments the reflectance signals was measured with time without stirring the water sample.

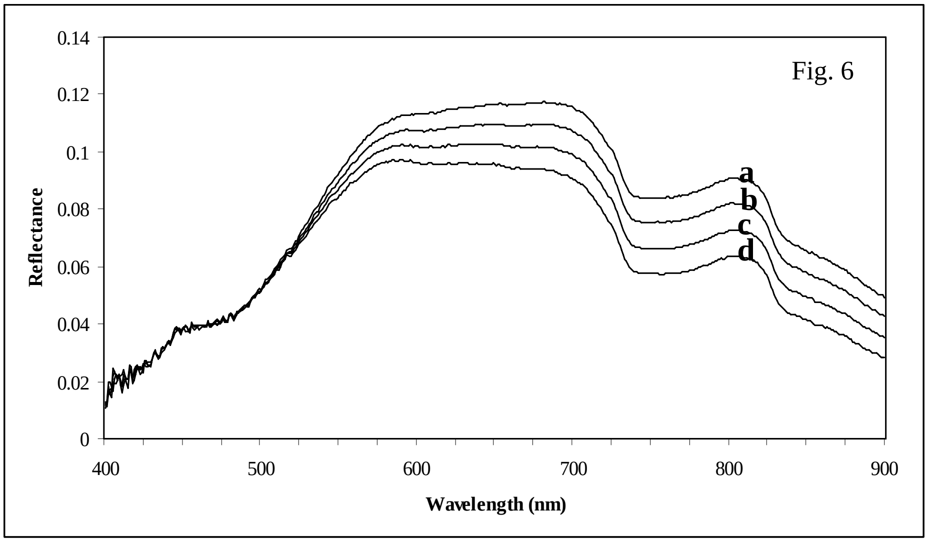


Figure 6. Spectral reflectance of water with constant concentration of clayey red soil (500 mg/l) a: Spectral reflectance after manual mixing 500mg/l clayey red soil b: spectral reflectance after 1 minute c: Spectral reflectance after 2 minutes d: Spectral reflectance after 3 minutes

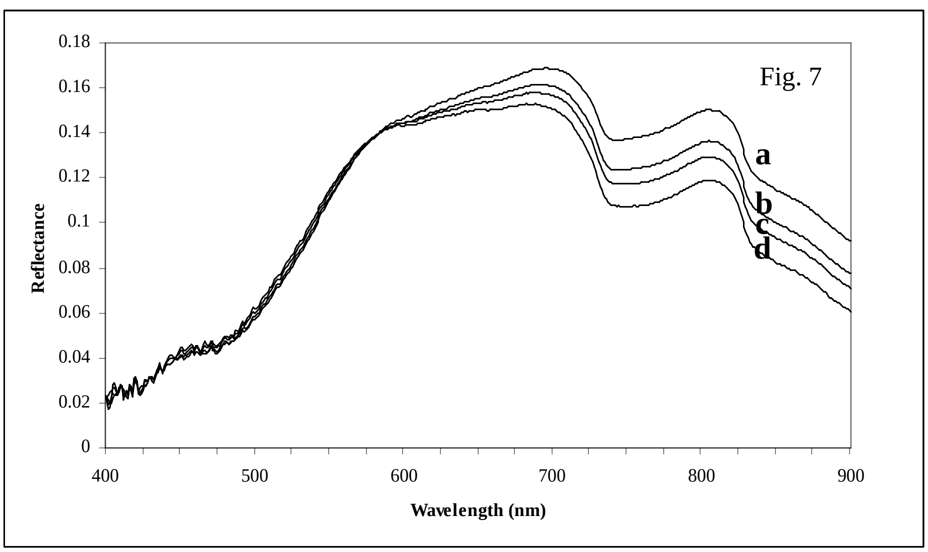


Figure 7. Spectral reflectance of water with constant concentration of clayey red soil (1000 mg/l) a: Spectral reflectance after manual mixing 1000mg/l clayey red soil b: spectral reflectance after 1 minute c: Spectral reflectance after 2 minutes d: Spectral reflectance after 3 minutes

Suspended sediments settled with time in the water and reflectance value changed with the change in sediment distribution and caused error in accurate estimation of suspended sediments. With the time the reflectance value decreases for the same amount of sediments owing to settling of sediment with time. Sediment grain size is one of the major factors for the distribution of sediments. These results indicate that the sediment distribution with depth affects the reflectance values significantly.

4 BAND RATIO MODEL DEVELOPMENT

Band ratio model was developed to investigate the relationship between suspended sediment and reflectance. This relationship is based on a simple reflectance ratio between near-infrared (825nm) and visible (560 nm) wavelengths. It was observed that strong correlation exists between SSC and the reflectance ratio of near-infrared & visible wavelength [Rrs (825)/Rrs (560)] as depicted in the figure. The polynomial function plotted on the graph (R^2=0.98) allows an accurate estimation of suspended sediments from Rrs measurements. It was also observed that in case of multispectral remotely sensed data (Landsat ETM), the ratios of band 4 & band 2 plotted against SSC will provide solution for the assessment of suspended sediments.

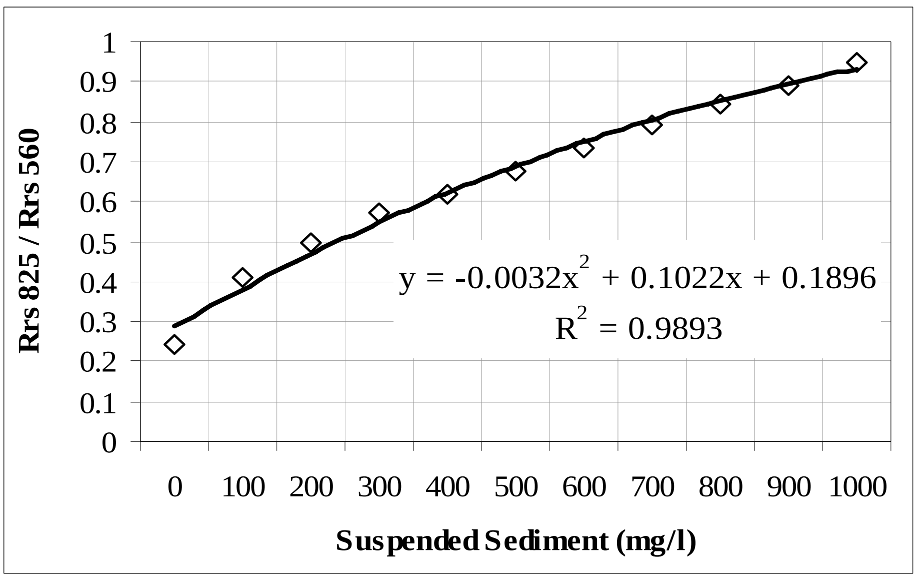


Figure 8. Ratio of reflectance [Rrs (825nm)/Rrs (560 nm)] plotted against suspended sediment (mg/l)

5 CONCLUSIONS

Soil characteristics (color, grain size, texture) are important parameters that influence the spectral reflectance of suspended sediment. With the increase in SSC, the reflectance signal increase uniformly with scattering in the visible domain and absorption in the near-infrared domain. Hence, it was concluded that the visible domain is useful from qualitative point of view and near-infrared wavelength is useful for quantitative assessment. The optimum wavelength for measuring SSC is 750 nm to 900 nm. However, visible wavelength 525nm to 650nm is found to be optimum for characterizing and differentiating suspended sediments. Assessment of suspended sediment concentration is important for basic and applied field application. Effect of suspended sediments distribution on the spectral signatures in water bodies needs to be explored for future research.

ACKNOWLEDGMENTS

The research work was financially supported by the Kochi University of Technology, Kochi Japan. The authors wish to acknowledge the financial assistance provided by the University. The assistance of all members of Nasu Lab is gratefully acknowledged.

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