OPTIMUM HYPERSPECTRAL MODELS FOR ESTIMATION OF SUSPENDED SEDIMENTS IN SURFACE WATER

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ABSTRACT

The purpose of the research was to estimate the suspended sediment concentration by means of remote sensing. Experiments were conducted to investigate the spectral response with different concentrations and types of suspended sediments in the water. In this research five cases were examined: clayey red soil, silty red soil, kaolin, silty red soil (50%) and kaolin (50%), and very fine sand. Fifty concentrations of suspended sediments ranging from 20 to 1000 mg/l were used is each case. A hyperspectral Field SpecPro FR Spectroradiometer attached to a telescope was used to measure reflectance from the water. A series of reflectance measurements in the spectral range between 400 and 900 nm was carried out in a batch. The band ratioing technique and regression analysis were applied to develop band ratio models.

Correlation coefficients (r) were computed to describe the relationship between suspended sediment concentration (SSC) and the reflectance. The ratios of reflectance values in the sub-bands centered at Rrs848/Rrs548, Rrs803/Rrs708, Rrs793/Rrs713, Rrs783/Rrs673, Rrs773/Rrs663, and Rrs773/Rrs658 were found to be optimum for estimation of suspended sediment concentration. The red and near-infrared (NIR) wavelength is a useful range for determining the amount of suspended sediments. However, the wavelength range 525-655 provides information about sediments type.

1. INTRODUCTION

Water resources and environmental management is essential for sustaining quality of life on earth. Soil erosion is a widespread problem causing the deterioration of both land and water resources. Globally the erosion rate has been estimated by many authors ranging between 0.06 mm/year and 0.16 mm/year (White, 2005). Sediment discharge assessment in the river basin provides a useful perspective on the intensity of erosion in upstream watershed. For estimation of the sediment yield one of the methods is the analysis of suspended sediment concentration and their relations to discharge at the outlet of catchment. Suspended sediment concentration measurement posses the advantage of providing a spatially integrated assessment of erosion rates in the upstream area. High concentration of suspended sediments in lakes and reservoirs accelerates the siltation process and thus shortens their life and efficiency. The loss of storage capacity in reservoirs in the

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United States cost $ 100 million annually in dredging and related mitigation efforts (Julien, 1995). Monitoring and modeling of suspended sediment is a difficult task because of many influencing factors. Suspended sediment monitoring stations are generally fairly sparse. Thus any extensive spatial resolution cannot be obtained. Some ad-hoc spatial monitoring campaigns do take place, however their expense and logistical difficulty prohibits extensive use.

Remote sensing holds potential for monitoring and estimating suspended sediments in surface water. Traditional methods of sampling and analysis are time consuming, labor intensive and provide only point data where measurements at any location on one lake, or even on many lakes, are generally necessary (Lodhi, 1997). The strength of remote sensing techniques lies in their ability to provide both spatial and temporal views of surface water quality parameters that is typically not possible from in situ measurements. Remote sensing makes it possible to monitor the water bodies effectively and efficiently and, identifying areas with significant water quality problems. Remotely sensed multispectral and hyperspectral data is widely touted by practitioners as providing solutions to the data problem. Remote sensing has been used extensively for the delineation of the surface water bodies. Remote sensing has an important role in water quality evaluation and management strategy. Monitoring large areas on a frequent basis can only be achieved economically with remote sensing (Engam 1991). 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 (Ritchie, 1988).

The suspended sediment concentration and reflectance relation depends on many factors including physical and optical properties of sediment type and sensor zenith angle (Kuo and Cheng 1978, Chen et al. 1991). The absorption and scattering properties of sediment type affect water reflectance (Novo et al. 1989). The presence of sediment in water changes the backscattering characteristics of the water dramatically. The synoptic view provided by remote sensing gives resource managers different type of data owing to large area coverage, timeliness and repetitive nature of satellite image, which is not possible from traditional surface data collection campaigns. The spectral reflectance of suspended sediment in surface water is a function of both the quantity and characteristics (particle size, texture, absorption) of sediments. It is imperative to determine the quantity and type of suspended sediments and optimal wavelength to enhance the reliability and applicability of remotely sensed data for water quality monitoring. Controlled experiments were conducted in order to investigate the effects of varying concentrations and types of suspended sediments on the spectral signature of the surface water. The purpose of the study was to examine correlations between remotely detected hyperspectral reflectivity and suspended sediment concentration in surface water.

2. MATERIAL AND METHOD

The research is based on the experiments conducted indoor at Kochi University of Technology, Kochi, Japan. The purpose of this research was to estimate the suspended sediment concentration by means of remote sensing. In this research work five cases were examined: clayey red soil, silty red soil, kaolin, silty red soil (50%) and kaolin (50%) and very fine sand. The red soil samples were collected from the central area of Okinawa Island (coordinates: 26º23´N and 127º73´E). Subsurface geology is diverse in this area with limestone, sandstone, phyllite, and gravels (Kubotera, 2006). The physical properties of the collected red soil were expected to be various, reflecting the diversity of parent materials. The percentage of clay was higher in the clayey soil. Kaolin and very fine sand was ordered commercially. The soil samples were air dried, pulverized and manually sieved to ensure a uniform particle size. To minimize extraneous reflectance, the experiments were performed in black room designed for experimental purpose using black coated tank. Two 500 watt tungsten halogen lamps uniformly illuminated from 1 meter above water surface with a beam inclination of 30^o were the sources of illumination during the experiment. The water tank is also black coated to reduce the influence of extraneous reflectance.

A hyperspectral Field SpecPro FR Spectroradiometer attached to a telescope was used to measure reflectance from the water. 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). For the purpose of this study, data from 400 to 900 nm (353 instrument channels) were used because of low signal-to-noise ratio problem at wavelengths outside this spectral range. The sensor was positioned perpendicular to the water surface at the height of 1 meter above the sample, yielding an instantaneous field of view 1.75 cm. The effects of atmospheric dispersion and absorption of light were considered negligible as the experiment was performed in black room under controlled condition and the distance of the sensor from the water surface was kept fixed during all the experiments.

Radiation input to the ASD Field Spec FR spectrometers is through a fiber optic, nominally 5 meters in length. The spectroradiometer was linked to a laptop, which stores the scans for each sample. The experiment was consisted of two parts. In the first part, the radiance of selected dry soil samples and in the second part radiance of water surface with varying concentration and types of suspended sediments was performed. Radiation of dry soil was measured indoor in black coated room. The soil samples were placed in black containers (15 cm in diameter and 6 cm in height). In case of dry soil samples contact probe was used to measure the radiation. However, in case of water with varying suspended sediment concentration 1 degree sensor was used.

The sieved soil samples were weighted to produce fifty concentrations of suspended sediments in each case ranging from 20 to 1000 mg/l. Initial reflectance readings were taken for the water tank prior to the addition of any suspended sediments and subsequently after sediments were mixed into the tank. The addition of each soil sediment produces suspended sediment concentration of level of 20 mg/l. The depth of water column was 60 am and was kept constant for all experiments. The soil sediments were kept in suspension by means of a mechanical diffuser and manually stirring at regular intervals. A stopwatch was used to monitor sampling intervals to ensure equal mixing times for each sediment addition and scanned time in order to minimize settling of input sediments. To improve the signal to noise ratio mean of ten scans were used in the analysis. All variables and procedure are kept identical for each case. Turbidity was measured by using PARTECH turbidity meter in mg/l in order to verify the homogeneity of suspended sediments and for comparison with SSC levels (M.A. Lodhi, 1997). Homogeneity of the suspended sediments in the water is imperative for accurate estimation of concentration.

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 (λ) is the radiance measured from the water surface, S (λ) is the radiance from the reference panel measured under the same illumination conditions and Cal (λ) is the calibration factor for the reference panel. The reference plaque was a Labsphere white Spectralon of dimensions 12.5cm x 12.5cm.

3. RESULTS And DISCUSSION

Many authors including Streck et al. 2003 have delineated the spectral signature of different type of soils. Spectral signatures of different dry soils sample are unique. It is possible to differentiate between different dry soils samples with varying texture and colors owing to distinct spectral pattern of reflectance as shown in Fig 1.

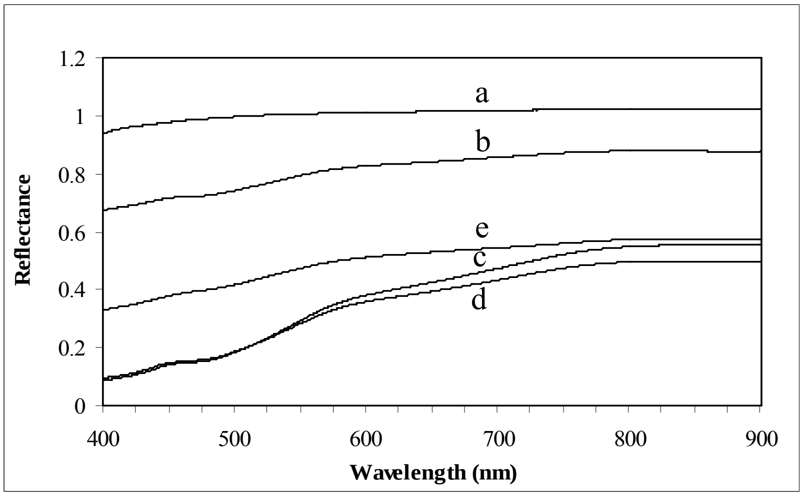

Figure 1 Spectral Reflectance of dry soils
(a) Kaolin (b) Kaolin 50% and Silty red soil 50% (c) Silty red soil (d) Clayey red soil (e) Find sand

All types of soils show a consistent characteristic signature. The reflectance value increase with the increase in wavelength in the visible and NIR domain. Kaolin (Curve a) has the highest reflectance, with about 25 % more reflectance than the mixture kaolin and silty red soil 50-50%. Dry fine sand showed higher reflectance as compared to clayey red soil and silty red soil. The higher reflectance of sand is because it is composed of quartz, which has higher reflectance VIS, NIR, and MIR compared to agricultural soils (Streck, 2003). Owing to soil characteristics and dark colour of clayey soil the reflectance value of silty red soil was found to be more than clayey red soil. The organic matter content in the dry soils samples was not measured as it was out of the scope of present study. However, previous studies have shown that organic matter content has a strong influence on the soil reflectance.

It is desirable to examine the spectral characteristic of the suspended sediments in the laboratory controlled environment. This could be useful to provide methodology to monitor the type, amount and spatial distribution of suspended sediments in water bodies. In order to investigate the concentration and type of suspended sediments in surface water, series of reflectance measurements in the spectral range between 400 and 900 nm was carried out in a black coated tank. Reflectance increase uniformly with the increase in suspended sediment concentration at all wavelengths between 400nm and 900nm as depicted in figure 2. An asymptote exists for sediment loading in surface waters, and the asymptote is different for various types of soil. Therefore, amount of suspended material and type are important factors in volume reflectance (Lodhi, 1997). Figure 2 shows the spectral reflectance of water with varying types of suspended sediments at SSC of 1000 mg/l. The reflectance value of kaolin as suspended sediments is higher as compared to other types of soils. Fine sand as suspended sediments has low value of reflectance. The find sand settle in the water and affect the accurate estimation of suspended sediment concentration. The reflectance of silty red soil as suspended sediments is more than the clayey red soil, which conforms with the results of numerous researchers.

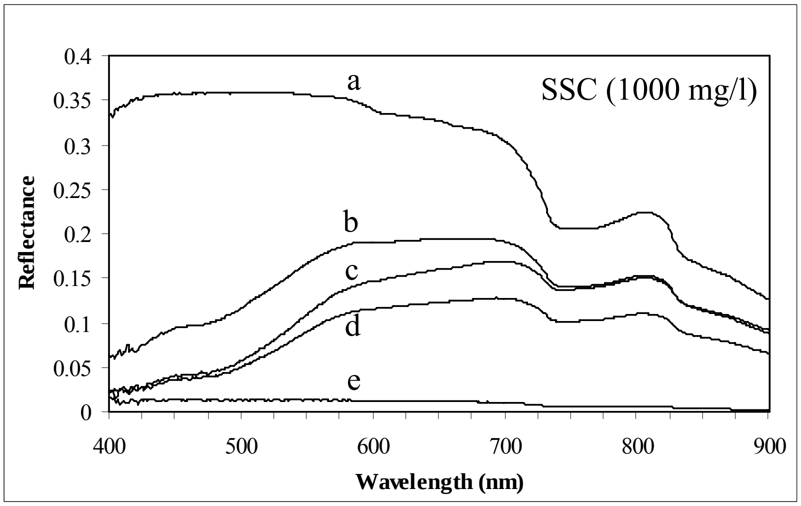

Figure 2 Spectral reflectance of water with different type of suspended sediments
(a) Kaolin (b) Kaolin 50% and Silty red soil 50% (c) Silty red soil (d) Clayey red soil (e) Find sand

Graphs were plotted to describe the variation of spectral reflectance with wavelength for different suspended sediment concentration (SSC) caused by different types of sediments (Figure 3).

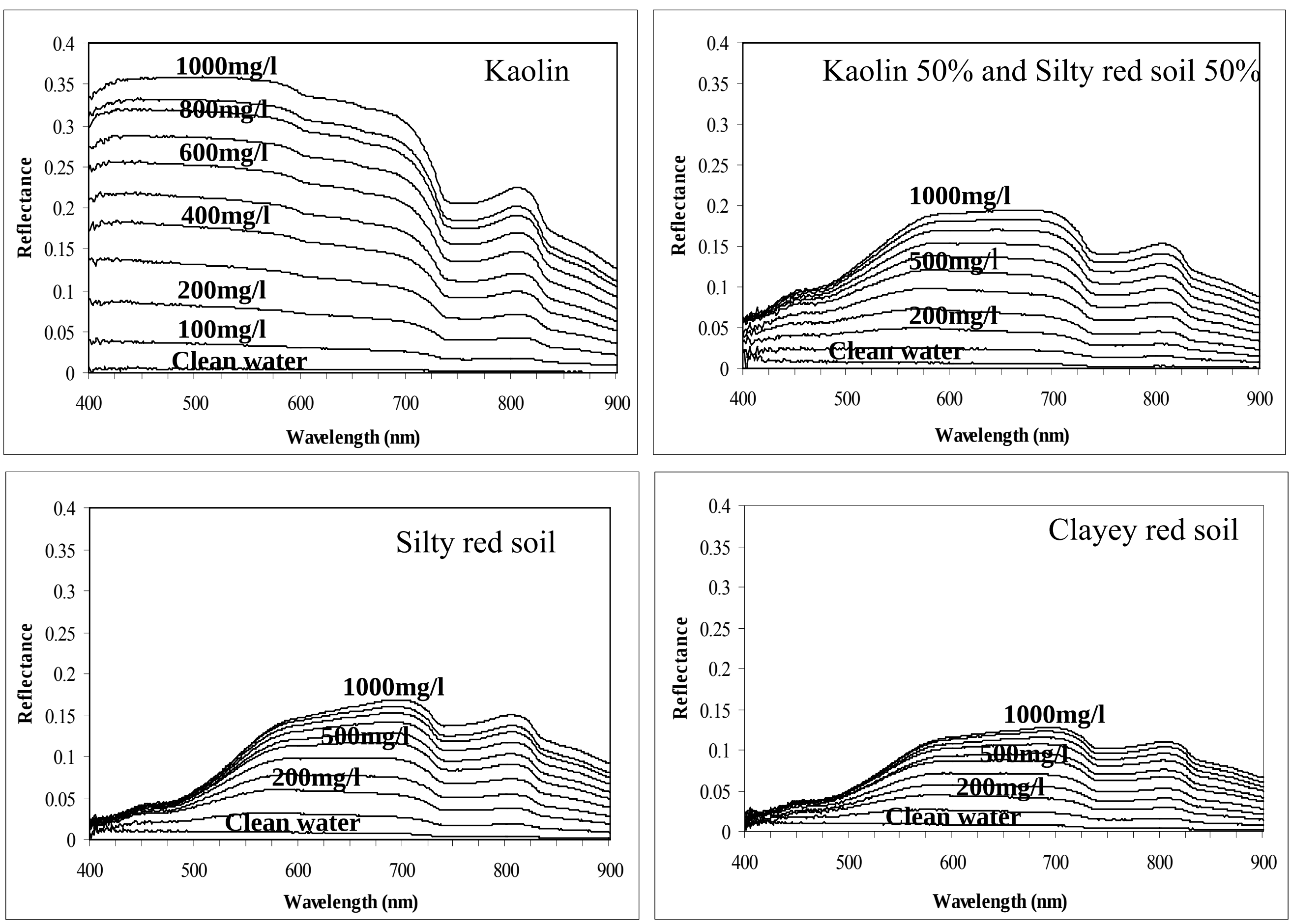

Figure 3 Spectral reflectance of water with varying concentration of SSC (mg/l)

The comparison of the graphs showed that optical signature trends are almost similar in case of kaolin, kaolin 50% and silty red soil 50%, clayey red soil, and silty red soil. A consistent increasing trend in reflectance was observed with the increase in SSC. Ritchie et al. (1976) using in situ studies concluded that wavelengths between 700 and 800 nm were most useful for determining suspended sediments in surface waters. It was observed that the red and near-infrared (NIR) wavelength 700-900 is a useful range for determining the amount of suspended sediments. However, the wavelength range 525-665 provides information about sediments type.

Suspended sediment in water has greater absorption of radiation at longer wavelength (Chen et al. 1991). It was observed that within the visible domain suspended sediments have no characteristic absorption. Fischer and Kronfeld (1990) suggested that scattering depends strongly on the complex refractive index and the size distribution of the particles. The mean refractive index of clay and non-clay minerals is higher than the refractive index of water (1.335). The mean refractive index of the clay minerals (1.540) is higher than the non-clay minerals (1.523) and the effect of variation in the refractive index is expected on the relation between the suspended sediment concentration and the reflectance.

The results obtained from the laboratory experiment indicated that the visible region were more useful than the longer near-infrared wavelengths for the information about type of the soil. The darker soil produced lower reflectance value than the light-coloured soil. In dry condition and as suspended sediments different soils can easily be distinguished from each other in the visible domain of 525-655 nm. It was observed from the figure 3 that the peak reflectance for each level and type of suspended sediment occurred in the visible domain and shifted towards longer wavelength with the increase in suspended sediment concentration. The peak is closely related to the amount of SSC. However, change in shift not only depends on the amount of SSC, but also on the type of the suspended material. The NIR wavelengths found to be more useful for estimation of suspended sediments.

In cases of find sand significant increase in reflectance was not observed with an increase in sediments concentration (Figure 4). This is because of texture and variation of grain size in fine sand. Different spectral reflectances were obtained for the different soil types of the same concentration because of the difference between the properties and characteristics of various soil types.

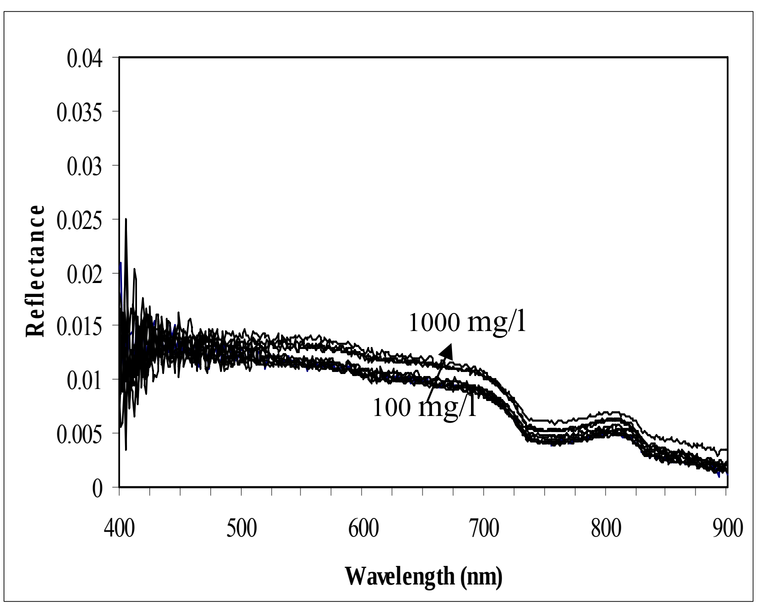

Figure 4 Spectral reflectance of water with varying concentration of fine sand (mg/l)

3.1 BAND RATIO MODEL

The band ratioing technique and regression analysis were applied to develop band ratio models. The spectral data were partitioned into narrow bands each having 5nm width. In total 100 centered narrow bands were generated, including 25 bands in blue domain, 16 bands in green domain, 10 bands in yellow domain, 19 bands in red domain, and 30 bands in NIR domain. Each narrow band is referred to, by its central wavelength.

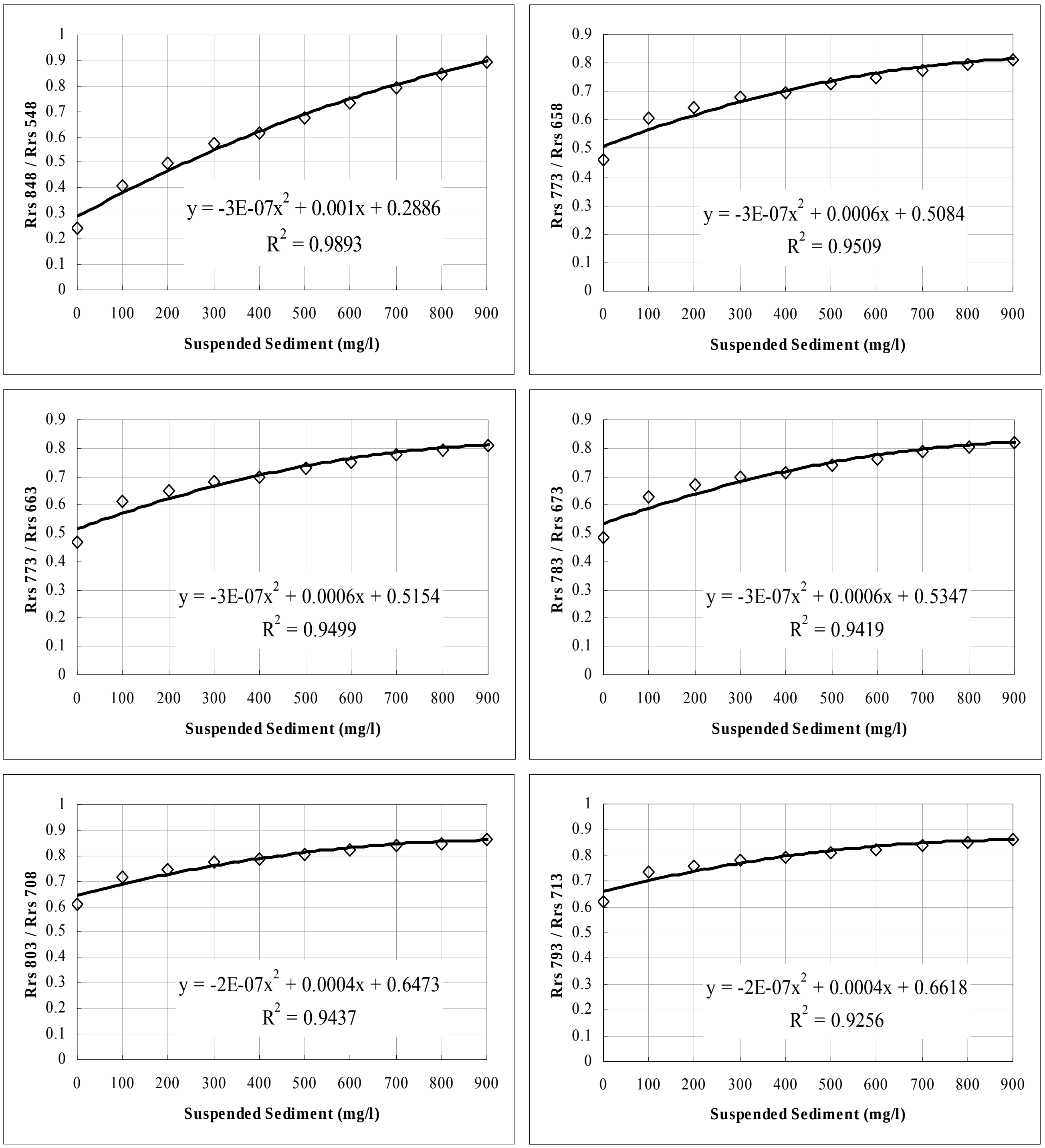

Figure 5 Band ratio models (Ratio of reflectance plotted against SSC)

Table 1 Development of Narrow Bands

Ratio (Bi/Gj)	RrsBi/ RrsGj	i=1 to 25	j= 1 to 16
Ratio (Bi/Yj)	RrsBi/ RrsYj	i=1 to 25	j= 1 to 10
Ratio (Bi/Rj)	RrsBi/ RrsRj	i=1 to 25	j= 1 to 19
Ratio (Bi/NIRj)	RrsBi/ RrsNIRj	i=1 to 25	j= 1 to 30
Ratio (Gi/Yj)	RrsGi/ RrsYj	i=1 to 16	j= 1 to 10
Ratio (Gi/Rj)	RrsGi/ RrsRj	i=1 to 16	j= 1 to 19
Ratio (Gi/NIRj)	RrsGi/ RrsNIRj	i=1 to 16	j= 1 to 30
Ratio (Yi/Rj)	RrsYi/ RrsRj	i=1 to 10	j= 1 to 19
Ratio (Yi/NIRj)	RrsYi/ RrsNIRj	i=1 to 10	j= 1 to 30
Ratio (Ri/NIRj)	RrsRi/ RrsNIRj	i=1 to 19	j= 1 to 30

Figure 5 shows the relationship between ratios of spectral reflectance and SSC. This relationship is based on simple reflectance (Rrs) ratio between visible and near-infrared wavelengths plotted against suspended sediment concentration. The ratios of reflectance values in the sub-bands centered at Rrs848/Rrs548, Rrs803/Rrs708, Rrs793/Rrs713, Rrs783/Rrs673, Rrs773/Rrs663, and Rrs773/Rrs658 were found to be optimum for estimation of suspended sediment. The regression models were developed and correlation coefficients (r) between ratio of spectral reflectance and SSC were computed to describe the relationship between suspended sediment concentration and the reflectance. The above spectral reflectance ratios and suspended sediments were found to be well correlated for clayey red soil, silty red soil, kaolin, and kaolin (50%) and silty red soil (50%). The computed r value was greater than 0.90 in all cases. However, in case of fine sand the computed r value range was 0.55-0.70. The rational is because the fine sand texture and grain size affect the spectral reflectance.

4. CONCLUSSIONS

On the basis of experimental results obtained from the present study it can be concluded that the intensity and spectral distribution of reflectance varied with type, texture, grain size and concentration of suspended sediments in surface water. Spectral reflectance for different types and concentration of SSC are uniqie. It was observed that the reflectance in the red and near- infrared (NIR) wavelength 700-900 is a useful range for determining the amount of suspended sediments. However, the wavelength range 525-665 provides information about sediments type.

Band ration models allow the accurate quantification of suspended sediments. The relationship is based on the simple reflectance ratio between near-infrared and visible domains. The ratios of reflectance values in the sub-bands centered at 848/548, 803/708, 793/713, 773/663, 783/673, and 773/658 were found to be optimum for estimation of suspended sediment in surface water. The results of the estimation of suspended sediment by using hyperspectral band ration models are encouraging. In this paper only the effect of suspended sediment amount and type on spectral reflectance was addressed. To develop more generalized model for predicting suspended sediment concentration, similar studies are needed to express and quantify the integrated effect of all such parameters on spectral reflectance.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the financial assistance provided by Kochi University of Technology (KUT), Japan. The authors gratefully acknowledge the assistance and cooperation of all the members of Nasu lab, KUT.

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