ASSESSING THE POTENTIAL OF REMOTELY SENSED DATA FOR WATER QUALITY MONITORING OF COASTAL AND INLAND WATERS

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Abstract: The objective of this research study was to assess the potential of remotely sensed data for estimation of water quality parameters in water bodies. The assessment was based on the field measurements, laboratory examination and data analysis of the collected hyperspectral reflectance data. The factors influencing the qualitative and quantitative nature of the spectra were also analyzed. The hyperspectral data is integrated into ALOS/AVNIR-2 band widths. Examination and correlation of simulated ALOS data reveals that multiplicative two band approach by using Band 4 (NIR) and Band 3 (Red) is best predictor of suspended sediments in water bodies. The ratio of ALOS/AVNIR-2 Band 3 and Band 1 was most closely correlated with Chl-a concentration. For estimation of total suspended sediments (TSS), a higher accuracy was achieved using the Band 4 / Band 2 ratios. Color dissolved organic matters (CDOM) were found to be well correlated with Band 1/ Band 2. Regression models were developed and the applicability of developed models was tested. The correlation coefficients with $R2 \geq 0.70$ elucidate the effectiveness of developed remote models for water quality monitoring. The developed algorithms have potential for estimation of water quality parameters in inland and coastal waters. The research work demonstrates an example for the feasibility of remotely sensed data for effective and efficient monitoring of suspended sediments, total suspended sediments, chlorophyll and (CDOM) in water bodies.

Keywords: Water quality parameters, Assessment, Remotely sensed data

1. INTRODUCTION

Synoptic information on water quality is difficult to obtain from a routine in situ monitoring network. The conventional point sampling campaigns do not give either the spatial or temporal view of water quality needed for accurate assessment and management of water bodies. Therefore, the difficulty of overall and successive water quality sampling becomes a barrier in water quality monitoring, forecasting and management. Remote sensing makes it possible to monitor the water bodies effectively, efficiently, and identifying areas with significant water quality problems. Remote sensing is a tool and technique that provides a platform for large-scale synoptic observations and continuous monitoring of water bodies.

Remote sensing techniques for monitoring coastal and inland waters have been under development since the early 1980's. The advantages of remote sensing are wider coverage of a satellite image, high and medium spatial resolution up to submeter, multi-spectral imagery, sometimes stereo mode, cyclic monitoring etc. On the other hand, the disadvantages are invisible in case of cloud coverage and night time for optical sensor, fixed time and date for acquisition and normally higher cost of the data [1]. The remotely sensed techniques for accurate monitoring of water quality parameters depend on the substance being measured, its concentration, influencing environmental factors and the sensor characteristics. Effectiveness of remotely sensed data in water quality assessment of different lakes and reservoirs has been examined by numerous researchers [2] [3] [4] [5]. From the remote sensing perspective, waters can generally be divided into two classes: case-I and case-II waters [6]. Case-I waters are those dominated by phytoplankton (e.g.

open oceans) whereas case-II waters containing not only phytoplankton, but also suspended sediments, dissolved organic matter, and anthropogenic substances for example some coastal and inland waters [7]. Major factors affecting water quality in water bodies are suspended sediments, algae (i.e., chlorophylls), chemicals (i.e., nutrients, pesticides, metals), and colored dissolved organic matter (CDOM).

The prime objective of the paper is to develop relationships between water quality parameters (WQP) and remotely sensed data (RSD). The criterion that has been taken in to consideration is the simplicity of the water quality model, accuracy, overcome influencing factors, and the potential application of the developed model at different time and place.

2. STUDY AREA

The research work to assess the potential of remotely sensed data for water quality monitoring was performed on three different rivers; The Monobe River, Kochi, Japan, Altamaha River, Georgia, USA, and the St. Marys River, Georgia, USA. The Monobe River is 68.12 km long and the basin area is 508.2 km^2, in which, mountain forest is 461.8 km^2, flat land is 38.2 km^2 and water course is 8.2 km^2. The Monobe River has three dams and two head works, namely Nagase Dam, Yoshino Dam, Suita Dam, Godo Weir and Togo Weir from upstream to downstream [8]. The Altamaha River in Georgia, USA drains one of the largest basins on the east coast. The watershed area of the river including its tributaries is 36,260 km^2. There is no dam on the river. The St. Marys River is in the southeastern United States. The river is approximately 144 km long. The research work at Altamaha River and St. Marys River was carried out as a joint research project with Center for Advanced Land Management Information Technologies (CALMIT), School of Natural Resources, University of Nebraska-Lincoln, USA.

3. METHODOLOGY

3.1 In situ measurements

The in situ water quality data was collected for the three rivers. In case of Monobe River the concentration of suspended sediments (mg/l) was prime parameter and only the suspended sediment (mg/l) data was collected, however, for other two rivers duplicate measurements were made for Chl-a, total suspended solids (TSS), salinity and CDOM. The spectral reflectance data for the same sampling points were was also collected.

3.2 Hyperspectral reflectance data

The spectral reflectance data of Monobe River, Kochi, Japan was collected by using Field SpecPro Hyperspectral FR Spectroradiometer. Reflectance was calculated as a simple ratio between upwelling radiance from the water surface and upwelling radiance of reference panel. 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.

$$R(\lambda) = [L(\lambda)_t / L(\lambda)_{cal}] \times R(\lambda)_{cal} \tag{3.1}$$

In case of Altamaha River and St. Marys River the spectral reflectance measurements were collected by a dual-fiber system, two inter-calibrated Ocean Optics USB2000 Spectroradiometers in the spectral range of 400nm to 900nm. Radiometer No. 1, equipped with a 250 field off view optical fiber was kept just below the water surface (3 cm) in the nadir direction to collect the subsurface upwelling radiance $L(\lambda)_u$. Radiometer No. 2, equipped with an optical fiber and a cosine collector was pointed upward to simultaneously measure the incident irradiance $E(\lambda)_{inc}$. To match their transfer functions, the inter-calibration of the radiometers was accomplished by measuring the upwelling radiance L_{cal} of a white Spectralon reflectance standard, simultaneously with incident irradiance E_{cal}. An average of 10 consecutive scans was used to collect the reflectance spectra at each of the sampling points. Percentage spectral reflectance $R(\lambda)$ was computed as:

$$R(\lambda) = [L(\lambda)_u/E(\lambda)_{inc}]\times[E(\lambda)_{cal}/L(\lambda)_{cal}]\times R(\lambda)_{cal} \tag{3.2}$$

$R(\lambda)cal$ is the reflectance of the Spectralon panel linearly interpolated to match the band centers of each radiometer.

4. RESULT and DISCUSSION

Field spectroscopy is a useful tool to understand the process and application of remotely sensed data. However, satellite and airborne optical sensors can provide the high spatial and temporal resolution data and have actual potential role for assessment of water quality parameters in surface waters. Satellite-based remote sensing provides one option for relatively low-cost assessment of suspended sediment concentration in surface waters [9]. Numerous researchers have applied remote sensing as a tool to measure water quality parameters and developed some algorithms in this endeavour. The band ratioing technique has proven to be advantageous because it tends to allow compensation for variations from atmospheric influences. The decision involving which bands to use is not always straightforward [10]. The four bands which are mostly correlated with water quality parameters are the blue, green, red and NIR. In order to investigate the filed applicability and feasibility of remotely sensed data to measure precisely the water quality parameters, the reflectance spectra of Monobe River, Altamaha River and St. Marys River was acquired. The acquired spectral signatures at the three rivers were integrated into ALOS/AVNIR-2 sensor band widths.

$$Band1 = \int_{420}^{500} R(\lambda) d\lambda \quad (4.1)$$

$$Band2 = \int_{4520}^{600} R(\lambda) d\lambda \quad (4.2)$$

$$Band3 = \int_{610}^{690} R(\lambda) d\lambda \quad (4.3)$$

$$Band4 = \int_{760}^{890} R(\lambda) d\lambda \quad (4.4)$$

The collected data was analyzed to develop the relationship between water quality parameters and remotely sensed data. Regression models were developed between the simulated ALOS/AVNIR-2 data and water quality parameters.

The reflectance spectra of Monobe River were acquired during different field campaigns under varying environmental conditions. Figure 4.1 depicts that there is a variation in the spectral magnitude and shape with maximum spectral reflectance of 24 percent. For brevity, the spectral data with high suspended sediment concentration is demonstrated. The spectral shape shows increasing trend with the increase in suspended sediment concentration. It is observed that the spectral shape of Monobe River water is almost same although the signals were acquired at different times of the year. The reason is that each field campaign is followed by heavy rain. The major constituent in the water is suspended sediments. The fine sediments brought by the feeding streams affect the spectral magnitude; however, it is observed that the type of sediments is almost same. The acquired reflectance spectra at Altamaha River and St.

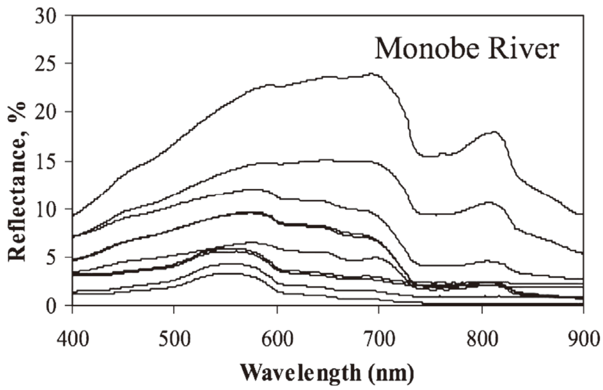

Figure 4.1 Spectral reflectance of Monobe River water acquired during field campaigns

Marys River demonstrate that the spectral signals are high at Altamaha River Figure 4.2: Subsurface spectra as compared to St. Marys River.

The rational is that TSS, Chl-a and turbidity is significantly high at the Altamaha River. The spectra were quite similar in shape with diverged magnitude for different sampling points. In case of both the river the reflectance was highly variable in the visible domain. The reflectance peak in green domain was 4.2 percent and 3.6 percent for Altamaha River and St. Marys River respectively and less than 1 percent in red domain for both rivers. The models were developed to assess TSS, Chl-a, CDOM, and secchi depth at Altamaha River and St. Marys River. The relationship between CDOM and salinity was also developed. Secchi depth is optical property of water and is strongly related with water constituents present in the water bodies.

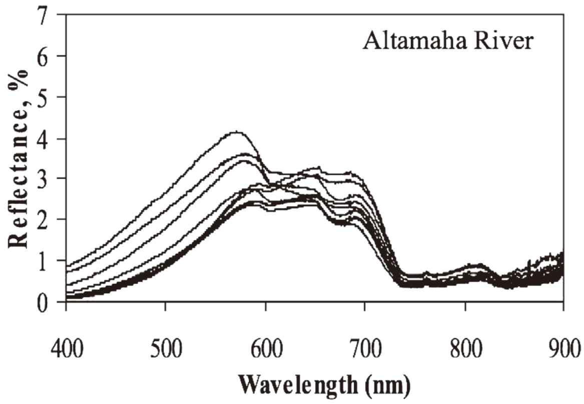

Figure 4.2 Subsurface spectra l signature of Altamaha River water

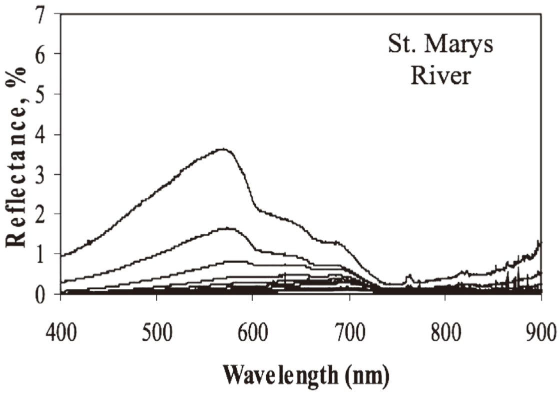

Figure 4.3 Subsurface spectral signature of St. Marys River water

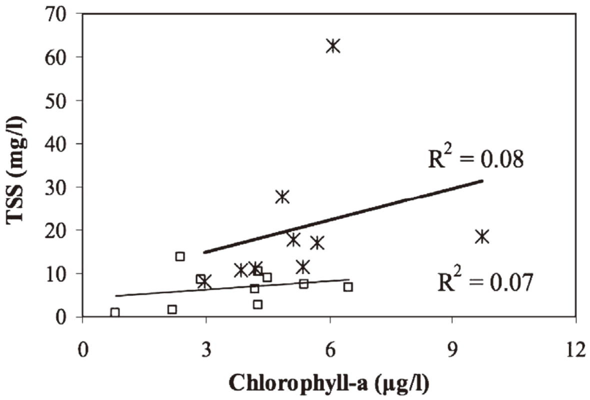

Figure 4.4 Relationship between TSS (mg/l) and chlorophyII-a (µ g/l)

The amount of TSS present in the water body defines the water category. Chl-a is commonly measured in water quality monitoring campaigns for costal and inland water bodies [11]. The advantage of the developed regression model is that the same model can be applied on both the rivers.

Both the rivers fall under the category of case- II waters. Chl-a concentration and TSS were not related (Figure 4.4) with the determination coefficient of linear relationship R¡0.08 and 0.07. It
depicts that Chl-a was not the only characteristic controlling water quality, confirming that the waters belonged to typical case-II water group. The ability to monitor water quality parameters in Case 2 waters requires high resolution remotely sensed data, quantitative and qualitative change in reflectance spectra, and the diverse nature of optical constituents present in the water body.

4.1 Suspended Sediments

The study of suspended sediments in water by means of remote sensing is complex and involves many factors that must be carefully taken into account. The magnitude and spectral shape varies with sediments type, texture, grain size and concentration of suspended sediments in surface water. The review of intensive literature demonstrate that the red and NIR region is best predictor of suspended sediment concentration. However, after the years of research the scientists and researchers are unsuccessful to develop global remote sensing model for estimation of SSC. Based on the data acquired during experimental work and massive field campaigns, the multiplicative 2 band algorithm (B4+B3)/(B3/B4) is strongly advocated for the prediction of SSC in water bodies. The Band 3 represents concentration of different suspended sediments ranging from very fine to medium size. However, the Band 4 characterizes the sediments near water surface representing very fine texture. The addition of Band 3 and Band 4 provides the spectrum features of low and high concentrations of the suspended sediments and provides solution for the estimation of different sizes of sediments within the water body. However, the influence of chlorophylla concentration on red domain (Band 3) is well documented in literature. To minimize the influence of chlorophyll on reflectance data, the resultant Band (B4+B3) is divided by the Band 3. This approach helps to minimize the influence of the chlorophyll on SSC. More precisely, by adopting this approach the influence of chlorophyll is minimized, however, the spectral signals disturb. The actual representative of suspended sediment in water bodies is Band 4. To develop model more accurately, the best approach is to multiply with the Band 4. The developed model for estimation of suspended sediments in water body is of following form;

$$\frac{B_4 + B_3}{B_3/B_4} \quad (4.5)$$

$$\frac{B_4 + B_3}{B_3} \times B4 \quad (4.6)$$

$$\left[\frac{B_4}{B_3} + 1\right] \times B4 \quad (4.7)$$

The simulated ALOS/AVNIR-2 bands, in combination, were used with regression techniques to define the relationship between reflectance and SSC to provide solution for the field application of remotely sensed data for assessment of suspended sediments. As illustrated in the figure 4.5, the correlation coefficient of 0.90 was

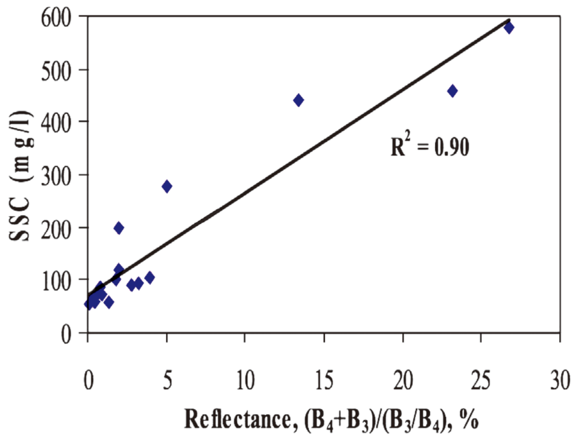

Figure 4.5 Relationship between developed model and SSC (mg/l)

obtained by applying the combination of two bands approach. The developed model is of the following form;

$$SSC = m\left[\frac{B_4 + B_3}{B_3 / B_4}\right] + n \qquad (4.8)$$

Where *m* and *n* are coefficient with values 19.5 and 69 respectively.

4.2 Total Suspended Sediments (TSS)

Total suspended sediments, inorganic and organic detritus contribute mainly to scattering of light. In general, the absorption of the total suspended particles is very low and is negligible for the inorganic particles. Inorganic particles are due to suspended sediments brought by the feeding stream. Total suspended sediments shows good correlation with NIR/Green (Band 4 / Band 2) band ratio. The NIR domain (750 900nm) absorbs in water and any reflectance in this range is because of suspended sediments present in the water body. However, the reflectance peak in green domain represents the amount of TSS present in the water body. The reflectance ratio of ALOS/AVNIR-2 *B*4 *B*2 shows correlation coefficient r = 0.73 for Altamaha River and 0.74 for St. Marys River.

$$TSS = m\left(\frac{B_4}{B_2}\right)^2 - n\left(\frac{B_4}{B_2}\right) + l \qquad (4.9)$$

Value of empirical coefficients for Althamaha River is m = 34.8, n = 127, l = 44, and for St. Marys River is m = 6.5, n = 17.4, l = 13

4.3 ChlorophyII-a

Phytoplankton cells are strong absorbers of visible light and therefore play a major role in determining the absorption properties of natural waters. The concentration of the main phytoplankton pigment, chlorophyll-a, is often taken as an index of phytoplankton biomass, although two major colour phytoplankton groups ? green and brown ? also contain chlorophylls-b and -c, respectively [12]. The chlorophyll-a is an indicator of the abundance of phytoplankton in the water. The pronounced scattering/absorption features of chlorophyll-a are: strong absorption between 400?500nm (blue) and at 680nm (red), and reflectance maximums at 550 nm (green) and 700nm (NIR) [13]. The scattering and absorption characteristics of chlorophyll-a can be studied when more than one band is used (Dekker et al. 1991). Keeping in view the absorption and scattering relationship, the reflectance ratio of R700/R670 is applied. The correlation coefficient R2 was 0.88 for Altamaha River and 0.71 for St. Marys River. A basic principle of using band ratios technique is to select two spectral bands that are representative of absorption/ scattering features of chlorophyll-a (Gin et al. 2002).

$$Chl - a = m\left(\frac{B_3}{B_1}\right)^2 + n\left(\frac{B_3}{B_1}\right) + l \qquad (4.10)$$

Value of empirical coefficients for Althamaha River is m = -0.12, n = 0.67, l = 4.5, and for St. Marys River is m = -0.02, n = 0.41, l = 3.2.

4.4 CDOM

Both fresh and saline waters contain varying concentrations of colored dissolved organic matters. These compounds are generally brown in color, and in sufficient concentrations can color the water yellowish brown. For this reason the compounds are generically referred to as yellow matter or CDOM, colored dissolved organic matter. Other common names are gelbstoff and gilvin. The presence of chlorophyll, TSS and CDOM usually dominate the water colour. The increase in the CDOM concentration affects the reflectance values in the blue and green region of the spectrum. CDOM absorption is characterized by a strong absorption in the blue wavelength region, exponentially declining towards longer wavelengths. To achieve a satisfactory degree of CDOM concentration retrieval the relationship between absorption by CDOM at 440 nm and band ratio (B1/B2) showed good correlation.

$$CDOM = m\left(\frac{B_1}{B_2}\right)^2 - n\left(\frac{B_1}{B_2}\right) + l \quad (4.11)$$

Value of empirical coefficients for Althamaha River is m = 64.7, n = 59.3, l =13.5 and for St. Marys River is m = 67.36, n = 58.7, l = 12.9

The relationship between CDOM and Salinity was developed with high degree of correlation.

$$Salinity = a \ln(CDOM, m^{-1}) + b \quad (4.12)$$

Value of empirical coefficients for Althamaha River is a = -10.2, b=12.7 and for St. Marys River: a = -10.3, b=23.4

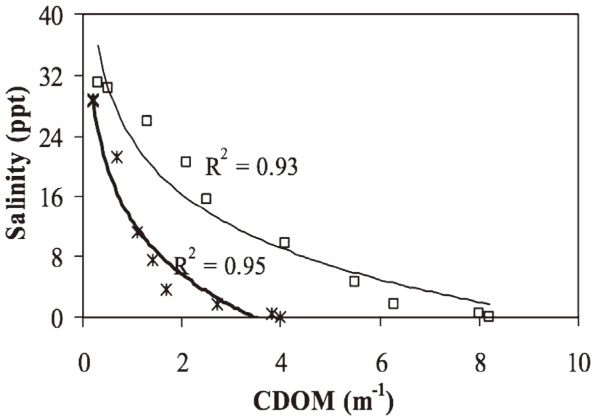

Figure 4.6 Relationship between salinity and CDOM

4.5 Secchi depth

Secchi disk is a subjective visual technique. And defines the optical transparency of the water. The maximum depth of visibility is called "Secchi depth ". This value is correlated with the optical properties of the water body and allows statements about the turbidity. The secchi depth is inversely correlated with the amount of TSS present in the water bodies. This method relies on human visual perception and much time and effort is required. The ratio of red and green domain B3/B2 provides information about the secchi depth.

$$SD = m\left(\frac{B_3}{B_2}\right)^2 2 - n\left(\frac{B_4}{B_2}\right) + l \quad (4.13)$$

Value of empirical coefficients for Althamaha River is m = 4.2, n = 5.7, l=7.9, and for St. Marys River is m = 5.8, n = 20.65, l=25.

5. Concluding Remarks

Remotely sensed data is effective to monitor water quality parameters and to develop a better understanding of light/water/substance intercations. Hyperspectral remote sensing allows accurate and potential use of entire range of electromagnetic spectrum recorded in extremely narrow wavebands for monitoring water quality on multiple sites in water bodies. Remote Sensing coupled with in site measurements is effective technique for monitoring water quality parameters. Remote sensing is a power tool to monitor the water quality potentially up to several times per year and offer valuable data on the seasonal variability of water quality. The ability to monitor water quality parameters in Case-II waters requires high resolution remotely sensed data, elucidation of quantitative and qualitative change in reflectance spectra and the diverse nature of optical constituents present in the water body.

The study of suspended sediments in water by means of remote sensing is complex and involves many factors that must be carefully considered. The multiplicative two band approach is effective for assessment of suspended sediments in water bodies. By adopting this approach, the influence of other parameters on suspended sediment assessment is minimized. It was found that the red domain and blue domain is well correlated with chlorophyll concentration and the ratio of simulated ALOS/AVNIR-2 Band 3/Band1 is well correlated with chlorophyll-a concentration. The ratio of NIR and green domain (Band 4/Band 2) is best predictor of TSS. Color dissolved organic matters (CDOM) were found to be correlated with Band 1/Band 2. It was noticed that CDOM and salinity are strong correlated and the salinity may estimated indirectly by applying developed CDOM and salinity relationship. The optical depth depends on the Chl-a and TSS concentration. The secchi depth and the ratio of Band3/Band 2 is well correlated and the ratio Band3/Band2 is found to be representative of optical depth in water bodies. The developed algorithms can be successfully applied for water quality monitoring. Empirical and semi-empirical algorithms are easy to use, however, the coefficients used in empirical algorithms are derived from data sets that do not necessarily represent all natural variations. The performance of such algorithms is always subject to compatibility between the waters under study and the waters from which data were obtained for algorithm development. The clear vision and understanding of relationship between water quality parameters and optical measurements made by means of remote sensing techniques is imperative for monitoring water bodies. This study demonstrates that the remotely sensed data can be a useful tool for monitoring the distributions of water quality parameters in coastal and inland waters. The water quality and quantity " Q and Q " connection " is vital for sustainable water resources development and management. Water should be recognized as a tool for community development and peace building. In the future, it will be important to incorporate water quality assessment as an integral part of water resources and environmental planning and management. Without this approach the problems of the water and environmental sector are going to compound in the future.

6. ACKNOWLEDGEMENT

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