Spectral Similarity Analysis Approach to Map Water Quality of Inland Waterbody

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ABSTRACT: Turbidity, an important quality parameter of water from its optical property point of view, its measurement on field in distributed manner is tedious and time consuming. Generally, band rationing, or regression analysis between turbidity concentration and band reflectance, approaches have been adapted to retrieve turbidity using multispectral remote sensing data, those result in qualitative rather than quantitative estimates of the turbidity. Over the past two decades, advances in sensor technology have overcome this limitation of earth observation systems, with the development of hyperspectral sensor technologies. Hyperspectral systems have made it possible for the collection of several hundred narrow contiguous spectral bands in a single acquisition. The hyperspectral remote sensing is emerging as the more in-depth means of investigating spatial, spectral and temporal variations in order to derive more accurate estimates of information required. In this study, the capabilities of the NASA's very recent Airborne Visible/Infrared Imaging Spectrometer Next Generation (AVIRIS-NG) airborne hyperspectral remote sensing data to map water quality of Chilika Lake, Odisha has been discussed. In the present study, spectral similarity analysis, between the spectral characteristics of AVIRIS-NG data and spectral library generated on field for the different concentrations of turbidity using field spectro-radiometer, has been done to quantify turbidity in the part of Chilika Lake, Odisha, India. For this kind of water quality mapping, a spatial spectral contextual image analysis technique "Spectral Angle mapper (SAM)" has been evaluated. It was found that, almost at each location in the lake under consideration, the field spectra matched with the image spectra with SAM score of 0.9 and more. The observed turbidity at each location was also very much falling in the estimated turbidity class range. It was observed that the spectral similarity approach provides more quantitative estimate of turbidity.

1. Introduction

In this ever-increasing population, the availability of potable water is scares. The comprehensive sampling of a large waterbody for its quality study is usually considered as costly and time consuming. Remote sensing techniques had played important role in assessing quantity and quality of available water resources over recent decades. A large number of documents have been published describing water quality monitoring using different multispectral sensor satellites (Quibell, 1991; Gitelson, et al., 1993; Han and Rundquist, 1996; Ritchie et al., 2003; Zhang et al., 2010). The spectral characteristics of the signal received from water are a function of hydrological, biological and chemical characteristics of water along with other interfering factors (Jerlov, 1976; Kirk, 1983; Ritchie et al., 2003; Cannizzaro and Carder, 2006; Wu et al., 2014). The slight change in their concentrations will change in the spectral signature/properties of the water. These changes in spectral characteristics of water can further be analysed to retrieve its quality. Initially, simple regression techniques were adapted for water quality monitoring, where the spectral response of particular band were correlated with concentration of particular water quality parameter measured on field (Chawira et al., 2013). Later, attempts have been made to identify sensitive bands for particular water quality parameter to analyse their concentration in water (Lacaux et al., 2007; Gardelle et al., 2010). However, with the advent of new sensor technologies with improved spectral and spatial resolution namely 'hyperspectral remote sensing', the quantitative assessment and monitoring of water quality are possible, as the technology provided spectral information of any feature on earth at contiguous narrow bands. Therefore, it is essential to study spectral characteristics of water and pollutants from water quality monitoring and assessment point of view.

2. Study area and data used

Chilika Lake, the largest coastal lagoon in India and the second largest lagoon in the world with width of 20 km and length of around 64 kms has been selected as study site. It is a brackish water lagoon, spread over the Puri, Khurda and Ganjam districts of Odisha state on the east coast of India, covering an area of over 1,100 km^2 as shown in Figure 1.

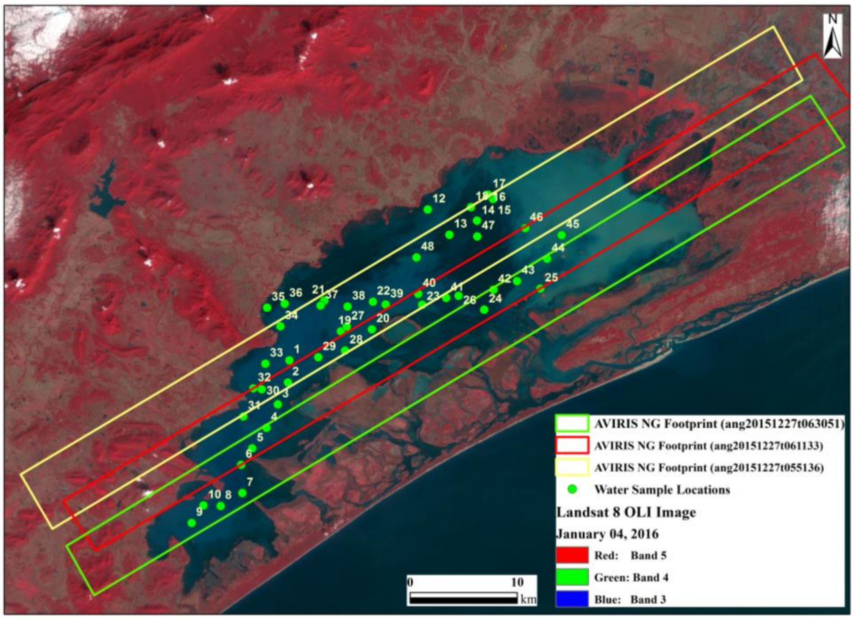

Figure 1. Chilika Lake as seen in Landsat 8 OLI Image along with location of sampling points and AVIRIS NG Footprints

The frequent change in physico–chemical properties and their interaction with each other in Chilika Lake makes it a unique experimental site. In 1981, Chilika Lake was designated as the first Indian wetland of international importance under the Ramsar Convention. At the northern end, tributaries of the Mahanadi River, such as Daya, Nuna and Bhargavi join the lagoon and are responsible for the large fresh water and sediment flux to the lagoon. The lagoon is separated from the Bay of Bengal by sand bar of 60 km length. The water quality of the lagoon changes widely with onset of different seasons and exhibits different ecological characteristics in localized pockets. The Chilika Development Authority's (CDA) physico–chemical investigations indicate highly turbid water due to strong mixing of overlying water with sediments, the transparency values ranging between 8 and 117 cm (Mahapatro et al., 2012). It has been also reported that the total sediment load discharged into the lagoon has increased from 1.8 M tones in 1998 to 2.94 M tones in 2001.

Under ISRO-NASA AVIRIS NG Airborne Hyperspectral Remote Sensing Flights Over India, the Site ID 100 was designated for Chilika Lagoon analysis. The AVIRIS NG radiance data (L1) has been collected from National Remote Sensing Centre, Hyderabad for this site ID. Each dataset have 425 spectral bands ranging from 375-2500 nm wavelength with a high spatial resolution of 8 m. The flying height of the sensor was around 8 km above the ground. The details of each dataset acquired on December 27, 2015 are given in Table 1 and their footprint are shown in Figure 1.

Table 1. Details of AVIRIS-NG Data Collected

S.No.	Site ID	Details of Radiance (L1) Data		
		File	Date	Time (IST)
1.	100	ang20151227t055136_rdn	Dec. 27, 2015	1120 hrs
2.		ang20151227t061133_rdn		1140 hrs
3.		ang20151227t063051_rdn		1200 hrs
4.		ang20151227t085136_rdn		1420 hrs

3. Methodology

An attempt is made to map water quality of Chilika Lake using the methodology shown in Figure 2. Initially, turbidity has been analysed using spectral similarity approach. Turbidity is an important quality parameter of water from its optical property point of view. The change in light attenuation by water column may deteriorate aquatic life and primary productivity, as well as the growth of aquatic vegetation (Ritchie et al., 2003). It varies spatio-temporally over large waterbodies and its well distributed measurement on field is tedious and time consuming.

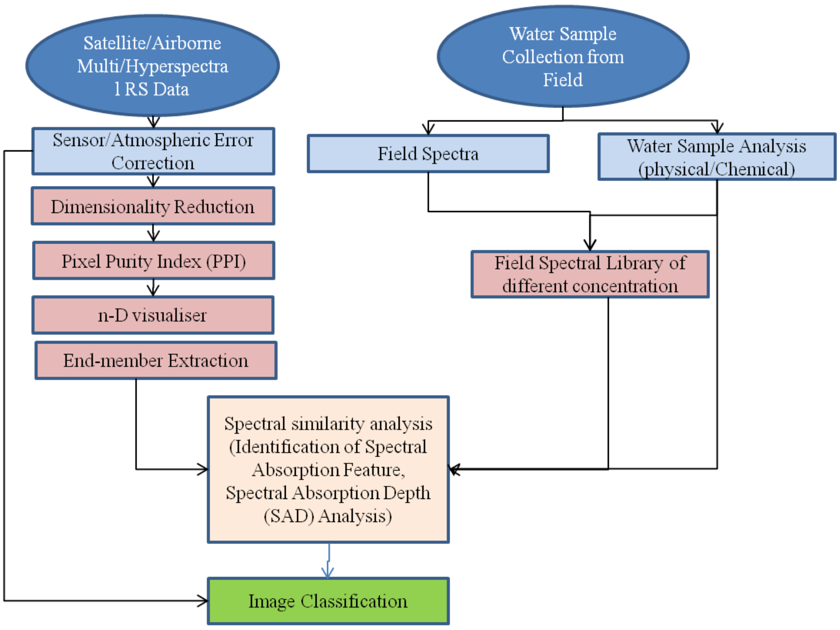

Fig. 2. Flow chart of methodology adapted

A spectral library was generated on field for the different concentrations of turbidity using well calibrated instruments like field spectro-radiometer, turbidity meter and hand held global positioning system as shown in Figure 3. The field spectra collected on field are shown in Figure 4.

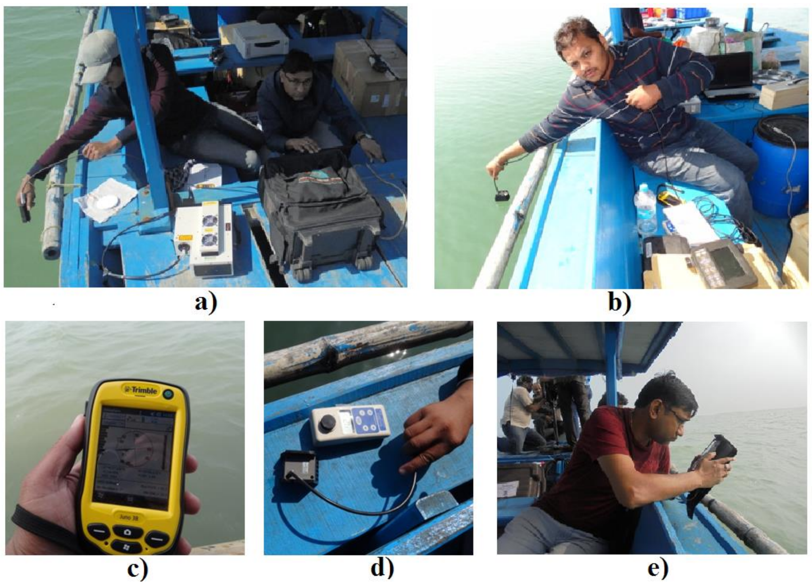

Fig. 3. Instruments used to collect ground data, a) field spectro-radiometer, b) portable eco-sounder, c) hand held GPS, d) turbidity meter, e) sun-photometer

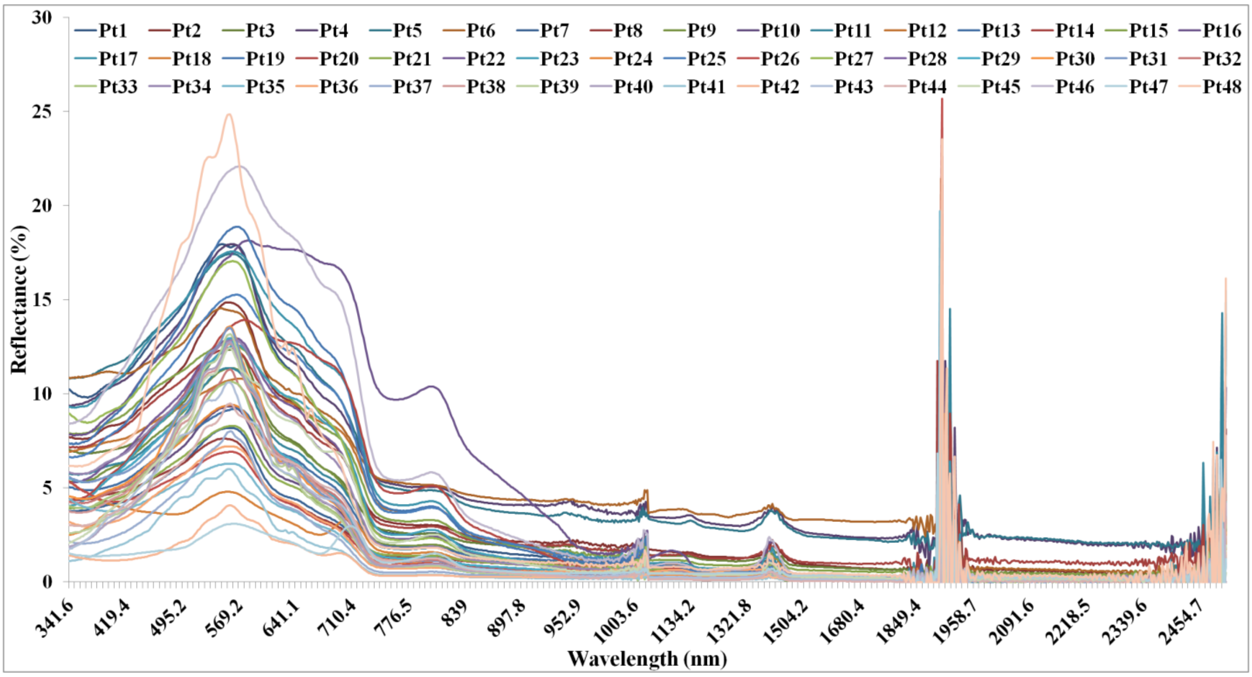

Fig. 4. Field spectra at each sampling point

AVIRIS-NG image was initially pre-processed using spectral subset technique and bad bands and columns were eliminated. The values of bad columns have been replaced by average radiance value of adjacent two columns. As water is sensitive in the spectral wavelength range of 400 - 1000 nm, the bands with wavelength over 1000 nm were remove to obtain 116 bands image for further analysis. The image was further atmospherically corrected using Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) which works on MODTRAN4 radiation transfer code.

In the present study, the most widely used SAM spectral matching algorithm has been adapted for mapping turbidity in Chilika Lake, India. SAM is a method for comparing image spectra to individual spectra or a spectral library. The algorithm determines the similarity between two spectra by calculating the "spectral angle (θ)" between them, treating them as vectors in a space with dimensionality equal to the number of bands (Kruse et al., 1993).

$$Cos\theta = \frac{\sum_{i=1}^{n} e_i r_i}{\sqrt{\sum_{i=1}^{n} e_i^2}\sqrt{\sum_{i=1}^{n} r_i^2}} \qquad (1)$$

where, θ is spectral angle, e is given image spectra, r is reference spectra, n is number of classes. This method is insensitive to illumination since the SAM algorithm uses only the vector direction and not the vector length. The SAM classification has been done on the reflectance image with the help of generated field spectral library using the spectral tools available in ENVI 5.0. After the classification, similarity of both the spectra (field and image) has been analysed at different locations. In the SAM spectral similarity approach, entire spectral library of field collected spectra were matched with AVIRIS-NG image spectrum at each pixel and their spectral angle 'θ' has been measured. Wherever, the least angle between two spectra has been measured, the turbidity class of that field spectrum has been assigned to that particular pixel. In this way, entire image has been classified according to their turbidity concentration.

4. Results

The SAM classification has been done on the reflectance image with the help of generated field spectral library using the spectral tools available in ENVI 5.0. The SAM classified image with respect to turbidity is shown in Figure 5. After the classification, similarity of both the spectra (field and image) has been analysed at different locations. For similarity analysis, it requires continuum to be removed from both the reflectance spectra prior to analysis. Six random points representing each turbidity class were selected and their spectral similarity has been studied after removing the continuum as shown in Figure 6.

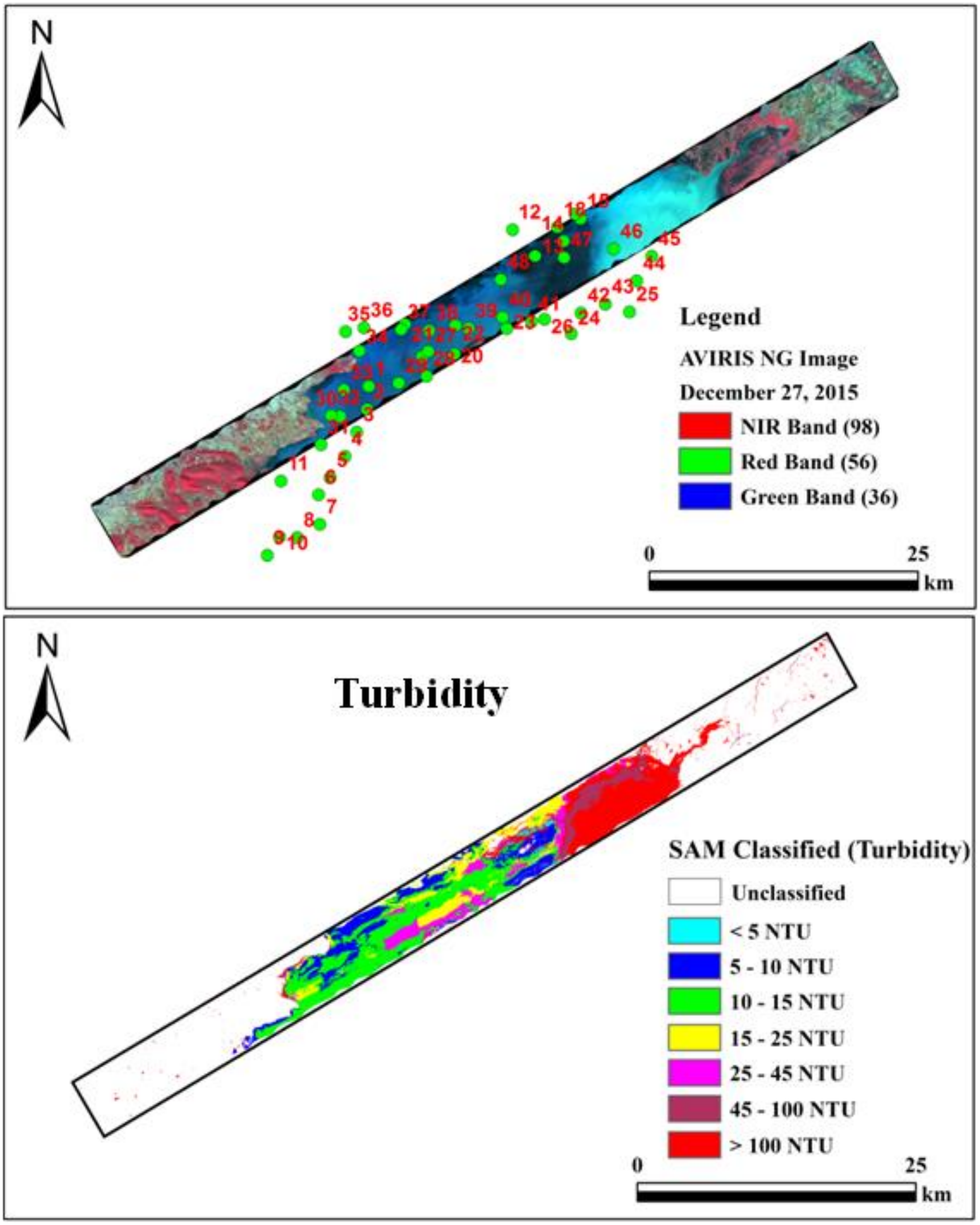

Figure 5. (a) FCC of AVIRIS-NG image of December 27, 2015 with location of sample collection sites (b) SAM classified image of the part of Chilika Lake

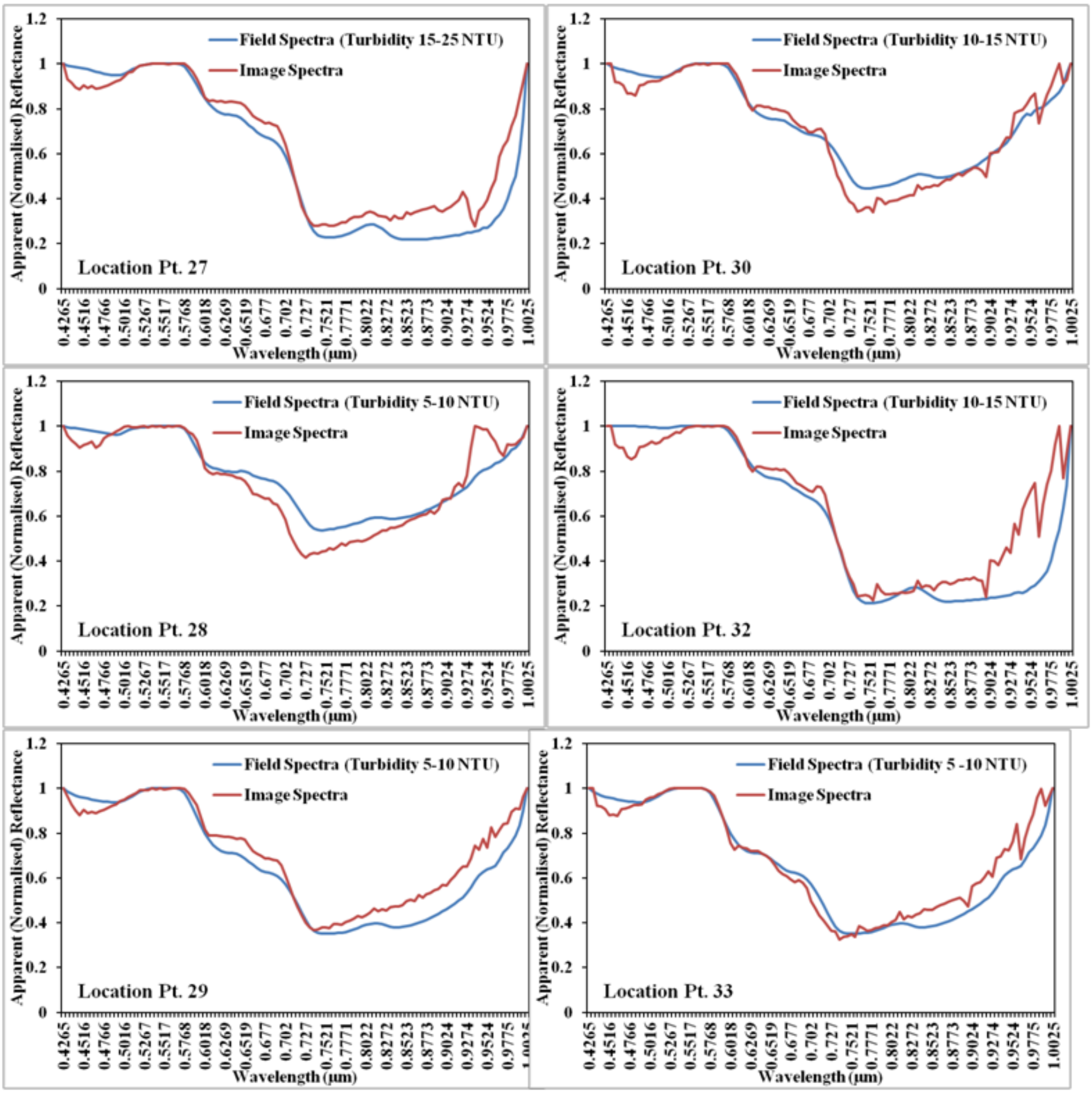

Figure 6. Field and AVIRIS-NG image spectra matching (continuum-removed spectra of selected locations for each class of turbidity)

The spectral similarity score of SAM spectral matching approach close to value of 1 indicates the closest match and higher confidence in the spectral similarity. At each location, the spectral similarity score found to be more than 0.9, which indicates better matching of two spectra (field and image). Chilika Lake, the highly productive ecosystem with its rich fishery resources sustains the livelihood of around 1.5 million fishermen who live in 132 villages on the shore and islands in the Lagoon (Ramesh et al., 2011). To conserve the high productivity of the lake, water quality studies are important.

5. Conclusions

The water quality of Chilika Lake with regard to turbidity concentration has been studied using spectral similarity approach. A spectral library, specific to Chilika Lake water quality parameters, has been generated using sophisticated instruments like field spectro-radiometer, turbidity meter and hand held GPS. The field spectral library has been resampled to AVIRIS NG bandwidth and used for spectral similarity analysis adapting most widely used SAM approach. A very high similarity between the image spectrum and field spectrum was found at almost each pixel. At the selected locations the SAM similarity score was usually higher than 0.9. As, the field spectra were classified into 7 classes of turbidity concentration as < 5, 5-10, 10-15, 15-25, 25-45, 45-100 and >100 NTU, SAM classified image resulted in these 7 classes of turbidity in the selected region of the lake. The SAM classification results were

quantitative in nature. Moreover, the observed turbidity concentration at different locations are well in the range of SAM classified results. The study shows usefulness of spectral library for water quality parameters and spectral similarity approach in water quality studies using imaging spectroscopy.
As the present study is an initial attempt in the direction of spectral library for water quality parameters and its application in spectral similarity analysis, a large number of recommendation needs to be followed in future research studies. The spectral library may further be improved by collecting field spectra in the different season with different conditions. The satellite image of same date of field campaign may improve the classification accuracy. The water quality assessment is a global issue, therefore, there is a need to set the protocols to develop standard spectral library with regards to water quality parameters and their concentrations. In this way, the water quality of any region on this globe can be assessed easily through geospatial technique.

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References

Cannizzaro, J.P., Carder, K.L., 2006. Estimating Chlorophyll a Concentrations from Remote-Sensing Reflectance in Optically Shallow Waters. Remote Sensing of Environment, 101, pp. 13–24.

Chawira, M., Dube, T., Gumindoga, W., 2013. Remote Sensing based water quality monitoring in Chivero and Manyame Lakes of Zimbabwe. Physical Chemistry of Earth, 66, pp. 38-44.

Gitelson, A., Garbuzov, G., Szilagyi, F., Mittenzwey, K.H., Karnieli, A., Kaiser, A., 1993. Quantitative Remote-Sensing Methods for Real-Time Monitoring of Inland Waters Quality. Int. J. Remote Sens., 14, pp. 1269–1295.

Gardelle, J., Hiernaux, P., Kergoat, L., Grippa, M., 2010. Less rain, more water in ponds: a remote sensing study of the dynamics of surface waters from 1950 to present in pastoral Sahel (Gourma region, Mali). Hydrol. Earth Syst. Sci., 14, pp. 309–324.

Han, L.H., Rundquist, D.C., 1996. Spectral Characterization of Suspended Sediments Generated from Two Texture Classes of Clay Soil. Int. J. Remote Sens., 17, pp. 643–649.

Jerlov, N.G., 1976. Marine Optics, Elsevier, Amsterdam, The Netherlands.

Kirk, J.T.O., 1983. Light and Photosynthesis in Aquatic Ecosystem, Cambridge University Press, Cambridge, United Kingdom.

Kruse, F.A., Lefkoff, A.B., Boardman, J.W., Heidebrecht, K.B., Shapiro, A.T., Barloon, P.J., Goetz, A.F.H., 1993. Airbone Imaging Spectrometry The spectral image processing system (SIPS)—interactive visualization and analysis of imaging spectrometer data. Remote Sens. Environ. 44, pp. 145−163.

Lacaux, J.P., Tourre, Y.M., Vignolles, C., Ndione, J.A., Lafaye, M., 2007. Classification of ponds from high-spatial resolution remote sensing: Application to Rift Valley Fever epidemics in Senegal. Remote Sens. Environ. 106, pp. 66−74.

Mahapatro, D., Mishra, R.K., Samal, R.N. and Patanaik, A.K., 2012. Study of macrobenthos in relation to eutrophication at Chilika Lagoon, East Coast of India. Marine Science, 2(6), pp. 139-148.

Quibell, G., 1991. The Effect of Suspended Sediment on Reflectance from Fresh-Water Algae. Int. J. Remote Sens. 12, pp. 177–182.

Ramesh, R., Purvaja, R., Senthil Vel, A., 2011. National assessment of shoreline change: Odisha coast. National Centre for Sustainable Coastal Management, Ministry of Environment and Forests, Govt. of India, Report 2011-01, 57pp. (available at http://www.ncscm.org/reports.php)

Ritchie, J.C., Zimba, P.V., Everitt, J.H., 2003. Remote Sensing Techniques to Assess Water Quality. Photogramm. Eng. Remote Sens. 69, pp. 695-704.

Wu, J-L., Ho, C-R., Huang, C-C., Srivastav, A.L., Tzeng, J-H., Lin, Y-T., 2014. Hyperspectral Sensing for Turbid Water Quality Monitoring in Freshwater Rivers: Empirical Relationship between Reflectance and Turbidity and Total Solids. Sensors, 14, pp. 22670-22688.

Zhang, M., Tang, J., Dong, Q., Song, QT., Ding, J., 2010. Retrieval of Total Suspended Matter Concentration in the Yellow and East China Seas from MODIS Imagery. Remote Sensing of Environment, 114, pp. 392–403.