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Assessment of water quality parameters of the Harike wetland in India, a Ramsar site, using IRS LISS IV satellite data

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Abstract This study aims at the classification and water quality assessment of Harike wetland (Ramsar site) in India using satellite images from the Indian Remote Sensing satellite, Resourcesat (IRS P6). The Harike wetland is a converging zone of two rivers, Beas and Sutlej. The satellite images of IRS Linear Imaging Self Scanner (LISS) IV multispectral sensor with three bands (green, red, and near infrared (NIR)) and a spatial resolution of 5.8 m were classified using supervised image classification techniques. Field points for image classification and water sampling were recorded using a Garmin eTrex Global Positioning System. The water quality parameters assessed were dissolved oxygen, conductivity, pH, turbidity, total and suspended solids (SS), chemical oxygen demand, and Secchi disk transparency (SDT). Correlations were established between turbidity and SS, SS and SDT, and total solids and turbidity. Using reflectance values from the green, red, and NIR bands, we then plotted the water quality parameters with the mean digital number values from the satellite imagery. The NIR band correlated significantly with the water quality parameters, whereas, using SDT values, it was observed that the green and the red reflectance bands were able to distinguish the waters from the two rivers, which have different water qualities.

Keywords River Beas · River Sutlej · Remote sensing · Secchi disk transparency

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Introduction

Remote sensing (RS) is a powerful tool that has been applied to regional water quality monitoring and assessment (Chopra et al. 2001; Choubey 1992; Kloiber et al. 2002; Nelson et al. 2003; Olmanson et al. 2002a, b). Studies have demonstrated reliable relationships between water quality parameters, such as total phosphorus, total nitrogen, dissolved oxygen, pH, salinity, Secchi depth, sodium and potassium, and radiance data from the satellites (Alparslan et al. 2007; Dewidar and Khedr 2001; Fuller et al. 2002a, b). The use of satellite imagery obtained from satellites has been used with reasonable accuracy to monitor water quality, and to derive key water quality parameters, allowing for continuous monitoring of water resources. The technique is time- and cost-efficient over large areas, and provides an effective tool for regular observation of even very remote landscapes.

Wetlands constitute integral components of landscapes, posses very high biological productivity, have tremendous resource potential and environment function (Hong-yu 1998), and are being looked upon as sources of food and as wildlife habitats, sustaining plants, animals, and even humans (WWF 1992). Their importance also includes flood control, natural sewage treatment, and recharging aquifers. Despite their vital functions, these uniquely important components of the landscape are being destroyed at an alarming rate. In some parts, especially in the developing world, where there is a high population growth, poverty, and scarcity of land, wetlands are still seen as potential agricultural lands, which threatens their existence. It is too late to restore many areas that have already been drained and reclaimed for agriculture or for urban expansion. Other serious threats faced by wetlands include siltation, nutrient enrichment, weed infestation, agricultural runoff, and pesticides.

These threats necessitate improved monitoring, restoration, and conservation. Proper management and conservation require regularly inventorying and monitoring the wetlands. RS, which is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with it (Lillesand and Kiefer 2000), is an effective way of gathering data for large-scale wetland surveys at a landscape level, and it represents a powerful alternative to aquatic surveys, which are often hindered by logistic problems (Silva et al. 2008). In Resolution VII.20, the Contracting Parties of the Ramsar Convention on Wetlands of International Importance recognized this importance to inventory and encouraged the collection of information for the management of shared wetlands, including those within river basins and/or coastal zones, a review and development of existing models for wetland inventory and data management, including the use of RS and low-cost and user-friendly GIS (Ramsar Convention 2006).

Routine water quality monitoring parameters such as dissolved oxygen, pH, salinity, Secchi disk, suspended solid matter, potassium, sodium, chlorophyll-a, and total nitrogen, total phosphorus, and relationships have been monitored using satellite images (Alparslan et al. 2007; Baban 1993; Dewidar and Khedr 2001; Kloiber et al. 2002; Min Wu et al. 2009), and studies have also demonstrated the use of RS for monitoring of water quality (Brezonik and Bauer 2003; Brezonik et al. 2005, 2007; Lillesand 2002; Schloss et al. 2002). However, the use of RS technology has rarely been used for water quality assessment for wetlands in India in general and Harike wetland in particular. RS can gather information that can be used for water quality assessment, augmenting the tedious field surveys (Li and Li 2004). The present study was aimed at (1) determining the relationship between some selected water quality parameters of the Harike wetland, (2) correlating the water quality parameters of the wetland with Indian Remote Sensing Satellite (IRS) Linear Imaging Self Scanner (LISS) IV multispectral data, and (3) determining whether IRS LISS IV data could be used to study the water quality of the wetland.

Study area

Harike wetland is the largest freshwater wetland in north India, covering an area of about 8,435 ha. It is an internationally recognized site (Anonymous 2008) that falls in the districts of Amritsar, Taran Tarn, Ferozepur, and Kapurthala in Punjab, India, between the latitudes 31°06′N and 31°12′N and longitudes 74°55′E and 75°05′E. The wetland is about 12 km long and 11 km in width and lies 55 km south of the city of Amritsar. A barrage was constructed in 1952 at the confluence of the rivers Beas and Sutlej, with the aim of storing and providing irrigation and drinking water to parts of southern Punjab, and to the adjoining state of Rajasthan. This created a manmade riverine wetland, which, over time, has emerged as a fine waterfowl habitat. Prior to the construction of Harike barrage, the area was marshy, riparian wetland, with small water channels and ponds around the confluence of the Sutlej and Beas (WWF 1992). The wetland is triangular in shape, with its apex in the west, a

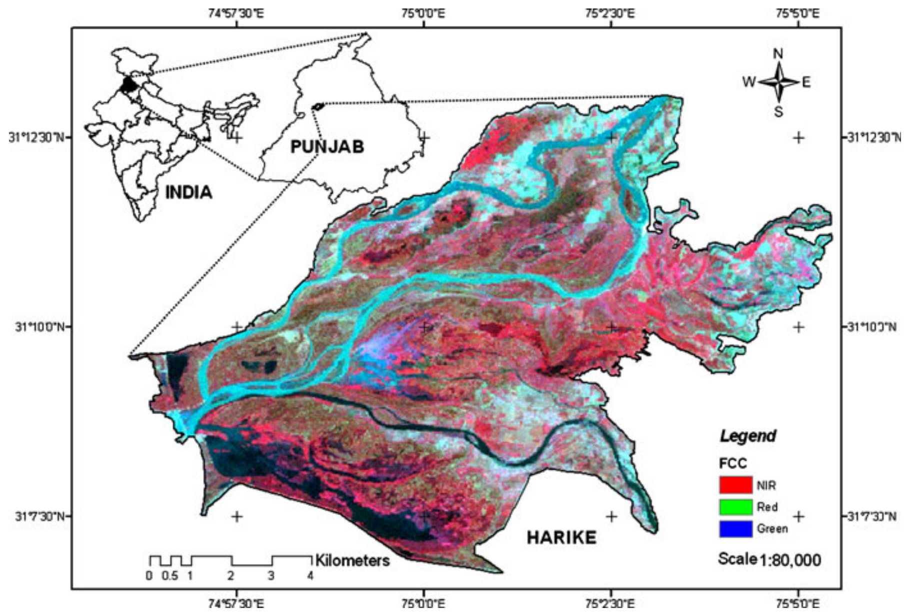

Fig. 1 Location of study area

bund, called the Dhussi bund, demarcating one side, a canal the second side, and a major road the third side (Fig. 1). The deeper portion of the wetland that constitutes the Harike Lake adjoins the barrage, whereas extending beyond this reservoir are stretches of marshy islands and shores that are characterized by shallow waters.

Harike wetland supports rare, vulnerable, and endangered floral and faunal species and attracts large populations of avifauna during the winters, which come from far-off places like Siberia and Eastern Europe. Very recently, six rare Indus dolphins (*Platanista gangetica minor*), a freshwater species classified as a critically endangered species in the Red Data Book of International Union of Conservation of Nature and Natural Resources, IUCN, (WWF 2008a), have been sighted in the wetland. There is an enormous concentration of migratory, as well as resident, waterfowl during the winters, and its importance as a waterfowl habitat has been recognized at various platforms. The Government of India declared it as a wildlife sanctuary in 1982. In 1990, under the Ramsar Convention, it was designated a Ramsar site and included in the List of Wetlands of International Importance. At the state level, it has been declared as bird sanctuary.

Over the years, Harike wetland has been facing a threat from a developing economy with increasing pressure on the resources (Chopra et al. 2001; Jain et al. 2008). Silt from the hill catchment deposited near the barrage, adjacent to the main reservoir, is reducing the water storage capacity of the reservoir and the amount of light penetrating into the water, thus minimizing fish production. Water hyacinth, *Eichhornia crassipes* (Mart.) Solms, a fast-spreading weed, covers a large area in the Harike wetland. It has reduced its size and blocks navigation by boats. Growth of this weed has been enhanced by raw sewage and industrial waste disposal from the upstream towns and villages along the rivers. The turbidity of the water in the two rivers is also variable, with Beas carrying most of the sediments into the wetland, while the water of Sutlej River is almost black due to the discharge of sewage and industrial waste water upstream in the industrialized city of Ludhiana, Punjab. The impact of the polluted water has viciously spread to other areas of southern Punjab and to Rajasthan, through the Harike waterworks.

Materials and methods

Satellite imagery

The Indian Remote Sensing Satellite, Resourcesat1 (IRS P6) LISS-IV multi-spectral data dated

Table 1 Image characteristics for LISS IV MX sensor

Sensor	Resolution					Swath (km)
	Spectral		Spatial (m)	Temporal (days)	Radiometric	
	Bands	Wavelength (μm)				
LISS IV MX	Band 2 (green)	0.52–0.59	5.8	5	7 bit	23.9
	Band 3 (red)	0.62–0.68				
	Band 4 (NIR)	0.77–0.86				

17 March 2006 were used for the study. This was acquired from the National Remote Sensing Agency's National Data Centre (NDC), Hyderabad. The image characteristics are given in Table 1. Satellite image processing software, ERDAS Imagine 8.4 and GIS software (ArcView GIS 3.2), were used to process and classify the satellite images. An eTrex, Garmin Global Positioning System (GPS) receiver, was used to determine the geo-coordinates of a given site in terms of its latitude, longitude, and altitude. GPS readings of patches of aquatic vegetation and water samples were taken. All GPS files were downloaded and exported as shape files and viewed on the image.

Image processing

The satellite image was geometrically rectified using ground control points (GCPs) collected from the field with a GPS. The root mean square (RMSE) for positional accuracy was of the order of 0.04 pixels. A survey was undertaken for collecting geo-coordinates along the wetland boundary. Using ArcView GIS 3.2 software, the geo-coordinates were converted to a shape file, from which a base map for the study area was prepared. The image was subset to extract the wetland area, which was used for further studies and analysis.

Water sampling and analysis

Water of the Harike wetland was collected from different sampling regions and analyzed in the laboratory. The collection, preservation, and analysis of water samples was carried out as prescribed in the standard methods (APHA 1989). Sampling site locations were collected using a GPS receiver. pH was tested using a systronics pH meter, Model 361, dissolved oxygen (DO) by the azide modification technique, chemical oxygen demand (COD) using the closed reflux titrimetric method where refluxing was done using a COD Reactor (AQUALYTIC Type AL 32 Block Digestor), with a capacity for eight 16-mm round cuvettes. A portable HM Digital COM-100 Waterproof EC/TDS/Temp Combo Meter with an EC Measurement Range of 0–9,990 μS was used for conductivity, and turbidity tested using a portable turbidity meter (PC COMPACT Turbidity Meter, AQUALYTIC), which is provided with standards (1, 10, 100, and 1,000) and has four measuring ranges 0–1, 1–10, 10–100, and 100–1,000 nephelo-turbidity units (NTU). The temperature of the surface water in the wetland was measured with a thermometer in situ (Michaud 1991). The Secchi disk transparency (SDT) was measured using a Secchi disk (Fuller et al. 2004; Michaud 1991). This is an 8-in-diameter disk, separated into four quadrants painted alternatively black and white, with a graduated rope that is attached to the disk and a bottom weight to keep it horizontal when it is being lowered slowly into the water. The disk was lowered into the water until it was no longer visible, and the depth recorded. It was then lowered past the point where it could no longer be seen, then raised slowly until it just reappeared and the depth again recorded. The average of the two depths was taken as SDT.

Satellite image classification

A field reconnaissance survey was performed to help in image interpretation and classification. Image classification was carried out using a supervised classification technique with the maximum likelihood algorithm approach. Sites on the ground were visited to collect training sets of a category, using GPS. The GPS points were overlaid on the image and the training sets were collected

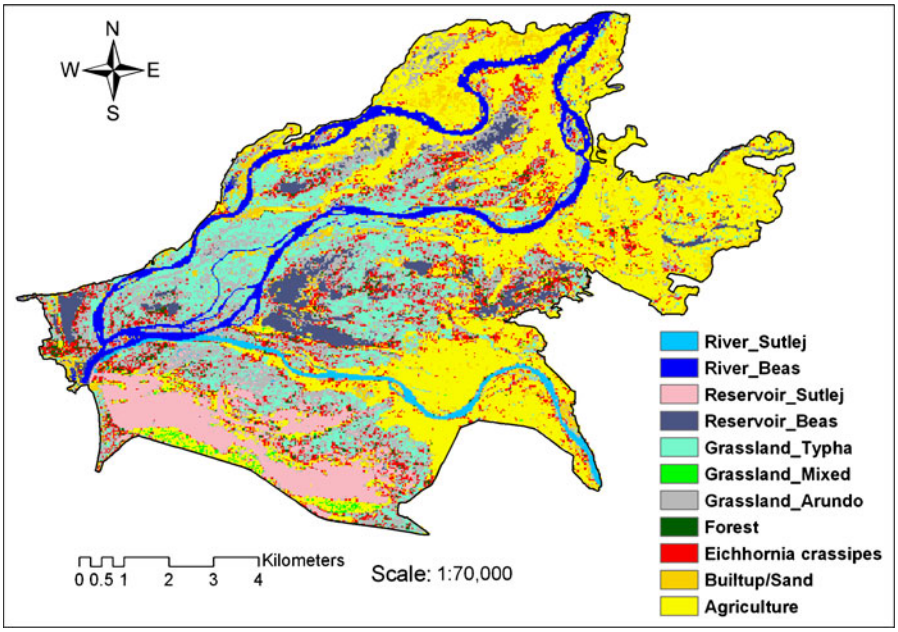

Fig. 2 Classified image of the study area

using an area of interest (AOI), in the image Viewer window of ERDAS Imagine, with the help of the "seed growing tool." A signature was developed by combining the spectra of all training set pixels for a given feature (ERDAS, Inc. 1999). The Signature file created was saved and used for the supervised classification. A thematic map of the wetland area with the vegetation cover types was produced in the classification (Fig. 2). Digital number (DN) values from the three bands (green, red, and near infrared (NIR)) of the satellite imagery were extracted from the image according to the standardized procedures by Olmanson (Olmanson et al. 2001, 2002a, b).

Results

The total area of the wetland was found out to be 8,435 ha and six broad categories were identified viz., water, grassland, forest, *E. crassipes*, agriculture, and built up/bare land. Their areas and percent covered for each class are given in Table 2. The water was segregated into four classes consisting of river Beas, river Sutlej, reservoir Beas, and reservoir Sutlej. It was found that the river Beas constitutes the bulk of the water flow into the wetland. There are two major reservoirs in the wetland, but most of the water in the wetland is stored on the reservoir towards river Sutlej, which

Table 2 Area under different classes in the Harike wetland

Class		Area (ha)	Percentage (%)
Water (1,495 ha) (17.72%)	Reservoir (Beas)	356	4.22
	Reservoir (Sutlej)	455	5.39
	River Beas	375	4.45
	River Sutlej	309	3.66
Grassland (2,649 ha) (31.40%)	Grass (*Arundo donax*)	1,552	18.40
	Grass (*Typha angustifolia*)	1,066	12.63
	Grass (other)	31	0.37
Forest/plantation		157	1.86
Eichhornia crassipes		742	8.80
Agriculture		2,866	33.97
Built up/bare		526	6.24
Total		8,435	100

constitutes 30% of the area with water compared to 23% of the area with water in the reservoir on the Beas side. Spectral disparity was exhibited for the water class in the digitally classified image, and it was possible to visually recognize three subclasses on the image, which consisted of the water class Reservoir_Beas and class River_Beas, and the third class consisted of two visually similar classes, i.e., class Reservoir_Sutlej and class River_Sutlej. However, when digitally classified, these two classes were distinguishable except for a small overlap in their spectra. The significance of the differences in the water in the two rivers was tested by employing Student's *t* test (Table 3), using Secchi depth measurements. We extracted pixels from different areas of Sutlej and Beas where Secchi measurements were taken and subjected the mean DN values from various bands and band ratios to the *t* test. The mean DN values were significantly different ($p < 0.001, n = 21$) for the three bands, suggesting the differences in the water quality of the two rivers.

Grasses are the dominant species of plants inside the wetland. The Harike wetland is dominated by the different species of *Typha angustifolia* L. (cattail), *Arundo donax* L. (giant reed), and other grasses. *Typha* spp. and the giant reed grow in large tracts, forming clusters. Using a GPS, it was possible to distinguish and map areas consisting of *Typha* and *Arundo* species. These species constitute areas of 1,552 and 1,066 ha respectively, the former with 18.40% of the total area and 12.63% for the latter. It was difficult to distinguish other grasses in the wetland as they are mixed and do not form clear stands. These have been grouped as a separate category called "grassland." Trees have been singly, sometimes, planted in groups along and inside the wetland area. Using clusters of tree plantations, it was possible to collect signatures from these areas and identify the trees as a separate class in the thematic map. Water hyacinth in the wetland grows in shallow marshes, and is found floating inside the wetland. It grows in patches large enough to be mapped. Therefore, it was possible to classify it as a distinct class. It occupies an area of 742 ha (8.80%). However, the weed is not stationary, and is carried by the wind waves on water from one place to another, especially where it is found floating. During release of water from the Harike waterworks, it is carried downstream through the two feeders. Due to this washing, the weed rises and falls, depending on the level of water in the wetland. Encroachment for agriculture occupies 2,866 ha, accounting for 33% of the calculated area. Built-up areas and sand bars have been clustered together as their spectral properties are indistinguishable. This class was observed mostly along the fringes of River Beas, where a lot of erosion is taking place, and in areas where there are deposits of sand from adjacent agricultural areas. The class also constituted small encroachments found in the wetland, which are used by the farmers to attend to their agricultural fields. Patches of sand inside the wetland, at the barrage where a major road passes, and the foot paths also represent this class. Accuracy assessment was performed, and this was accomplished by comparing the pixels on the map with reference data obtained from ground checks using a GPS. The results of the classification showed an overall accuracy of 81.40%.

Table 3 Comparison of means of pixel values in different bands and band ratios for the rivers Beas and Sutlej

Bands	Pixel values (means ± SD)		t-value
	Beas	Sutlej	
Near infrared (NIR)	14.52 ± 1.093	11.94 ± 0.867	6.019*
Red (R)	42.83 ± 1.531	22.38 ± 1.555	30.310*
Green (G)	47.90 ± 1.437	29.05 ± 1.003	35.140*
G/NIR	3.32 ± 0.365	2.442 ± 0.162	7.277*
R/NIR	2.96 ± 0.178	1.884 ± 0.196	13.134*
NDVI = (NIR – R)/(NIR + R)	0.49 ± 0.023	0.304 ± 0.047	11.705*

*$p < 0.001, n = 21$

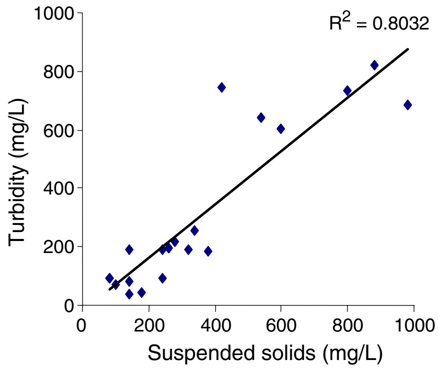

Fig. 3 Plot between suspended solids and turbidity

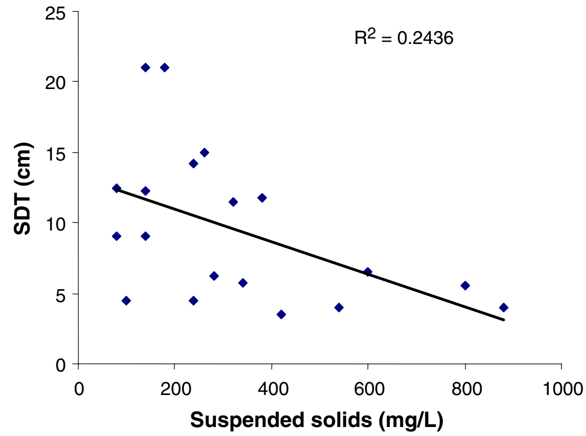

Fig. 5 Plot between suspended solids and SDT

Correlation between the water quality parameters

Nineteen water samples were collected along river Beas and Sutlej and in the wetland reservoirs. These were analyzed for DO, conductivity, pH, turbidity, total solids, total suspended solids, COD, and SDT. Plots for suspended solids and turbidity, total solids and turbidity, suspended solids and SDT, and total solids and SDT are given in Figs. 3, 4, 5, and 6. Significant correlations were obtained between turbidity and suspended solids ($R^2 = 0.8032$, $p < 0.001$, $n = 19$), total solids and turbidity (0.9104, $p < 0.001$, $n = 19$), suspended solids and SDT ($R^2 = 0.2436$, $p < 0.05$, $n = 19$), and total solids and SDT ($R^2 = 0.6785$, $p < 0.01$, $n = 19$). Other parameters showed no significant correlations. DO in the Harike wetland was found to vary widely, with some of the areas having DO as low as zero. This was observed on the river Sutlej side of the wetland, due to the presence of high organic matter leading to depletion of oxygen by biological decomposition, as shown by high COD values ranging from 320 to 472 mg L^{-1}. Conductivity values were observed to be quite high, with the Sutlej water showing values up to 1,260 µS cm^{-1}. The lowest conductivity value was recorded in the river Beas (178 µS cm^{-1}). While pH values ranged between pH 7 and 8, higher values were observed from the river Sutlej, and the lower from the reservoir of the Beas.

Turbidity in the wetland varied from 39 to 820 NTU. It was observed that river Beas had overall

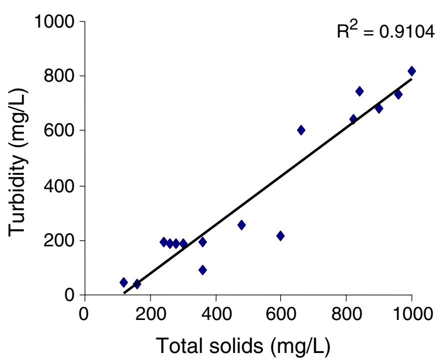

Fig. 4 Plot between total solids and turbidity

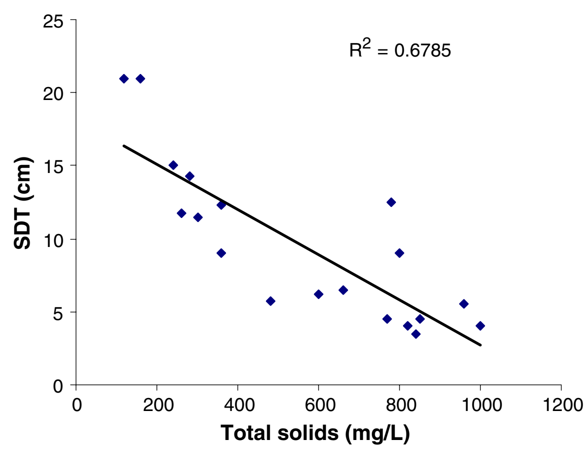

Fig. 6 Plot between total solids and SDT

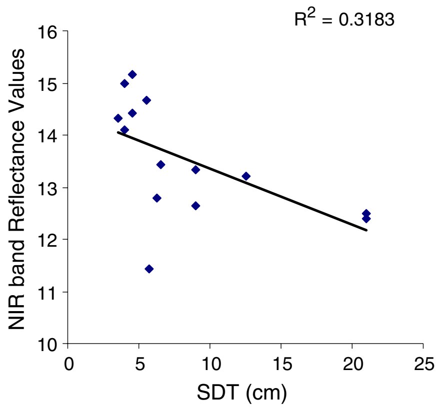

Fig. 7 Correlation between SDT and NIR band

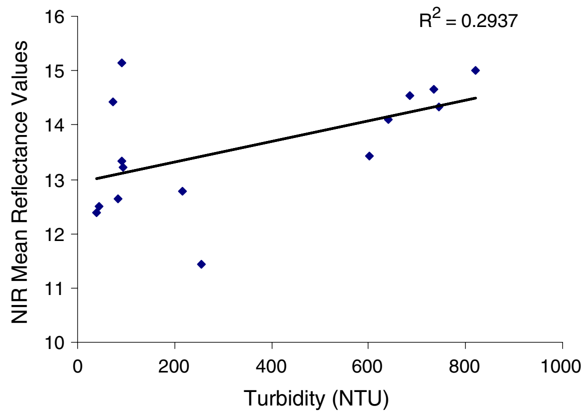

Fig. 9 Correlation between turbidity solids and NIR band

high turbidity values due to the presence of more suspended solids in the river measuring up to 880 mg L^{-1}. Total solids were also comparatively higher in river Beas, with 1,000 mg L^{-1} as the highest recorded value. When the turbidities were compared with SDT values, it was observed that high turbidities were associated with low SDT values. The SDT values ranged from 3.5 to 77.6 cm, with an average of 24.41 cm. The highest Secchi reading was recorded in the Reservoir_Riyasat, which has clear water as observed in the satellite imagery. The minimum value was obtained from river Beas, which remains turbid most of the season.

Correlation of water quality parameters with satellite reflectance data

Water quality parameters were correlated with the multispectral data. The spectral reflectance values from all the bands of the image were correlated with four water quality characteristics, viz., SDT, turbidity, total solids, and suspended solids (Figs. 7, 8, 9, 10, 11, and 12). Correlations were made between SDT, total solids, turbidity, and suspended solids, and the NIR mean reflectance values (Figs. 7, 8, 9, and 10). The correlations were shown to be significant for total solids ($R^2 = 0.5268$, $p < 0.01$), SDT ($R^2 = 0.3183$, $p < 0.05$), and turbidity ($R^2 = 0.2937$, $p < 0.05$). However,

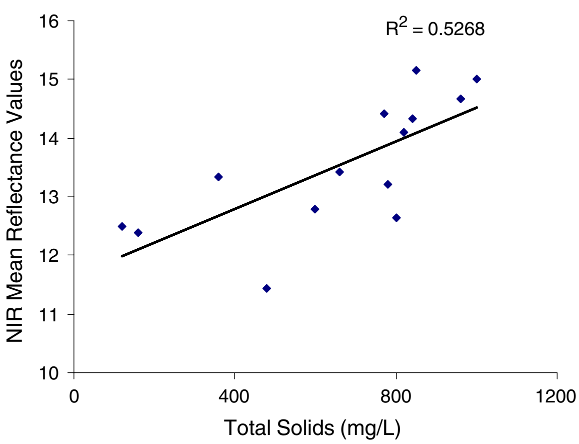

Fig. 8 Correlation between total solids and NIR band

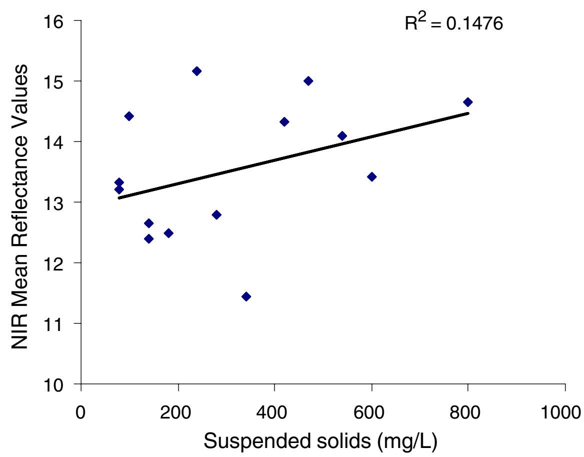

Fig. 10 Correlation between suspended and NIR band

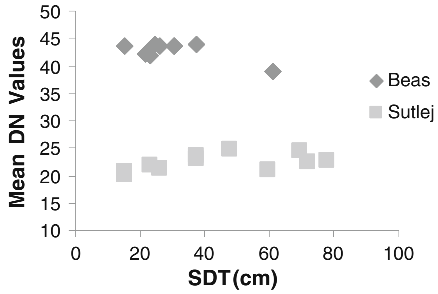

Fig. 11 SDT and green band

suspended solids showed no significant correlation with NIR. Reflectance values from the red and green bands did not show correlation with any of the water quality parameters. However, plots between SDT measurements as taken from different points of the rivers Beas and Sutlej, and from the two reservoirs, and reflectance values from the red and green bands, showed that the two waters are spectrally distinguishable in the two bands (Figs. 11 and 12).

Discussion

Satellite RS studies for estimating water quality are based on statistical relationships between the spectral reflectance by pollutants being measured and the ground data (Li and Li 2004). Therefore, any assessment of water quality using RS will depend on the physical, chemical, and biological properties of water (Seyham and Dekker 1986). RS data for the Harike wetland generally showed that its water quality has deteriorated, especially on the Sutlej river side. Observations revealed that the two rivers have different water qualities (Figs. 4, 5, 11, and 12) and that the water samples collected from Beas and Sutlej retained their identity. Turbidity differs in the two rivers, being higher on the Beas side as revealed by correlating Secchi disk measurements with the satellite data. We observed distinct spectral properties at the confluence, suggesting that the two water loads do not mix easily at the confluence even when they flow down to the canals. It was also observed that, when turbidity was high, the clarity of the water was reduced. Turbidity in the Beas River is due to coarse dispersions, especially during the monsoon floods. However, the river remains murky throughout the year as it traverses long distances, receiving contributions from farming and other activities that disturb the soil along the river. Large amounts of silt, contributed from the fringes of the river, also remain suspended in the river. On the other hand, water quality of the Sutlej is influenced by industrial wastes as it passes through urban areas, notably, along the city of Ludhiana and other small cities such as Talwara, Goindwal, Nawanshar, and Ropar, much of which is untreated. Turbidity in this river is caused by organic and inorganic substances from industrial wastes.

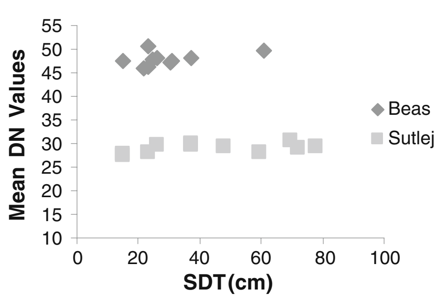

Fig. 12 SDT and red band

Clear water is generally associated with better water quality as compared to turbid water. SDT measures the clarity of a water body; thus, it can be used as a low-cost and effective quantitative measure of water quality. In very turbid waters, suspended solids influence transparency of the water; therefore, SDT is related to the turbidity of a water body, and is used as an indicator of the concentration of suspended solids. Water bodies that are low in turbidity have high SDT values (high water clarity), and those that are high in turbidity have low SDT values (low water clarity). Highly turbid waters have a higher concentration of suspended sediments than less turbid waters. TDS in water comprises of inorganic salts (principally, Ca, Mg, K, Na, bicarbonates, sulfates, and chlorides). It also contains small amounts of organic matter dissolved in water originating from natural sources, sewage, urban runoff, and industrial wastes. The incidence of high conductivity values indicates the presence of high content of dissolved salts in the river Sutlej. It was observed that the water quality in the wetland falls within the optimum pH range, viz., 6.5–9.5, required for consumption (WHO 2006). However, turbidity levels were high, and this is often associated with higher levels of disease-causing microorganisms. As per the WHO guidelines, drinking water should have a turbidity value of less than five NTU.

Aquatic vegetation of the Harike wetland forms separate and stratified stands, which have been mapped using a GPS. Difficulty in mapping water hyacinth was experienced due to the mobile nature of the plant. The plant is sometimes washed away, especially when the water is released at the barrage for irrigation downstream. Abundance of water hyacinth in the wetland, therefore, depends on the level of water where the weed is found floating. In the presence of large stands dominated by a single species of plants, it is easy to identify aquatic vegetation without any difficulty using RS (Anderson 1990), whereas plants that do not form clear stands offer difficulty in their distinction in the classified image. Ladhar (2002) reported that unauthorized encroachment from the public is one of the greatest threats to the Harike wetland. With 34% of the wetland used for agriculture, there is an impact on the water quality due to eroding of soil from cultivated areas adjacent to the wetland into the rivers. This not only changes the turbidity but also contributes pesticides and fertilizers adsorbed in the soil sediments. Areas in the wetland under fishing and grazing show little vegetation. It has been observed that a deep-seated area near and around the reservoir on the Beas side, Riyasat, shows minimal vegetation disturbances because there is no access to the general public into this area. Riyasat showed the lowest turbidity values, ranging from 39–43 NTU. Other parameters, such as total solids (160 mg L^{-1}), suspended solids (140 mg L^{-1}), and COD (32 mg L^{-1}), have also been shown to be comparatively low. Highest SDT value (77.6 cm) has also been recorded in this area.

Conclusion

It is therefore concluded that IRS LISS IV bands 2 (green), 3 (red), and 4 (NIR) can be used to quantify the water quality of Harike wetland. Green and red bands are suitable especially for distinguishing the water quality with respect to Secchi disk measurements. Water from the river Beas is distinguishable from that of river Sutlej on the basis of DN values extracted from the sampling areas. We also observed significant correlations for NIR DN values with total solids and turbidity for the LISS IV data. A negative correlation was observed between SDT and the NIR DN values.

There is an utter need for the conservation of Harike wetland and its endangered fauna and to provide a perennial source of good-quality water to the people. The factors contributing most to the deterioration of the wetland are industrial effluents, sewage, and agricultural runoff rich in fertilizers and pesticides. All this results in the eutrophication of the lake, which leads to extensive growth of *E. crassipes*. In order to protect the wetland and its rich fauna, it is warranted that the water that is being discharged into Sutlej and Beas be pretreated through common effluent and sewage treatment plants. It is desirable to have green belts along the riverside to check the flow of silt and agricultural runoff into the rivers. Water hyacinth should be periodically harvested. The agencies involved in the management of Harike wetland, the Forest and Wildlife Department, Irrigation Department, and the Punjab Pollution Control Board, among others, with Punjab State Council for Science and Technology acting as a nodal agency, act in isolation in their conservation efforts (WWF 2008b). There is an urgency to conserve the international wetland through strict enforcement of the law to save it from polluting industries, and by way of implementation of ameliorating measures.

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