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Multispectral Remotely Sensed Models for Monitoring Suspended Sediment: A Case Study of Indus River, Pakistan

Asif M. Bhatti, Seigo Nasu and Masataka Takagi

Department of Infrastructure Systems Engineering,
Kochi University of Technology, 782-8502, Kochi, Japan

Abstract: Soil erosion is a widespread problem causing the deterioration of both land and water resources. The water quality and quantity "Q and Q" connection is vital for sustainable water resources development and management. The prime objective of the research work is to quantify suspended sediment concentrations in surface waters by means of ALOS and ASTER satellite data. In this research work multispectral data and optical modeling is integrated to cope with lack of ground truth data. Modeling and monitoring of suspended sediment in water bodies is complex owing to many influencing parameters. Remote sensing makes it possible to monitor the water bodies effectively and efficiently and is most successfully used as part of a multidisciplinary approach to addressing natural resource questions. The strong relationship between suspended sediments and water surface reflectance leads to develop the efficient and effective algorithms for suspended sediments assessment in water bodies. Reflectance of ALOS/AVNIR-2 Band 3 and Band 4, ASTER Band 2 and Band 3N was found to be the best predictor of suspended sediment concentration in surface waters. The developed model and monitoring system is a useful practical tool for monitoring suspended sediments on seasonal bases and during floods. The research work demonstrates the feasibility of remotely sensed data for monitoring sedimentation in water bodies with and without ground truth data.

Key words: ALOS • ASTER • Suspended sediments • Monitoring • Algorithm

INTRODUCTION

Most of the problems in water resources and environmental sector are common in arid and semi-arid regions of the world. These are generally: water quality and quantity problem, soil erosion, inadequate storage and sedimentation in water bodies. It is universal truth that meager resources compel for their better utilization and preservation. Soil and water resource protection is crucial for productive and sustainable economies. Soil provides ecological capacity by delivering a range of functions including food and fiber production, biodiversity, landscape and heritage, raw materials and physical platforms for the built environment. High concentrations of suspended sediment in river waters are a critical element in the economic feasibility of a project and could shorten the useful life of many reservoirs and dams. Assessment of suspended sediment volume carried by a river is vital for an adapted water resources management strategy. South Asia is one of the regions in the world where soil erosion by water and wind is a severe problem [1]. The problem of soil erosion and sedimentation is more severe in developing countries, where the watershed management is not considered in the past. The design and sizing of many hydraulics structures require a pre-determined knowledge of the quality and quantity of suspended sediments carried by the river waters. This necessitates a comprehensive study of sediment carrying capacity of streams, the quantity of total sediment deposited in reservoirs, the particle size of the sediment and the quantitative relation of sediment to the flow of water. Distribution of the suspended sediment concentration in the rivers is the key issues for analyzing the intensity of erosion in upstream watershed and its adverse effect on the downstream areas.

The loss of storage capacity in the United States reservoirs cost $ 100 million annually in dredging and related mitigation efforts [2]. The most often cited estimates of the global suspended sediment discharge to the ocean range between 15×10^9 t•yr•^{1} to 20×10^9 t•yr•^{1}

Corresponding Author: Asif M. Bhatti, Department of Infrastructure Systems Engineering, Kochi University of Technology, 782-8502, Kochi, Japan

where the best estimate may be about $20\times\times10^9$ t•yr•^{1} [3], of which over 25% is considered to be trapped by dam reservoirs [4]. Identification of these sources and quantifying their effect is a major task for environmental technologist and water resources planners [5]. In order to cope with demands for new information to underpin the development of sediment control and management strategies, particularly in those areas where sediment problem have attracted attention, there is dire need to explore new sources of data to complement traditional data collection techniques.

Arguments for the application of remotely sensed data for water resources and environmental monitoring is compelling. Global problems require global solutions and these in turn require information on a global scale. Information is the combination of knowledge and observation. Earth observation data must be combined with knowledge in order to improve the scientific understanding of the entire earth system. Earth observation from space offers unique opportunities to obtain information regionally and globally. Remotely sensed data offer a unique perspective and are imperative for management and monitoring of earth resources from local to regional to global scale. Remote sensing techniques for monitoring coastal and inland waters have been under development since the early 1970's. The range of optical water quality properties that can be successfully estimated by remote sensing include total suspended matter, chlorophyll-a, suspended sediments, turbidity, colored dissolved organic matter (CDOM) and vertical attenuation coefficients of downwelling (K_d) and upwelling light. Remotely sensed data provide synoptic indication of the distribution of water colour and its associated physical properties in water bodies. The goal of environmental remote sensing is to obtain information on the nature and properties of the objects on the earth's surface and in the atmosphere. The common approach is to use the data from sensors which record the electromagnetic radiation reflected or emitted from those objects [6]. There are a number of areas in water resources and environmental monitoring that can benefit from remotely sensed data.

The application of remote sensing in water resources research and management mainly lies in one of the three categories: mapping of watersheds and features, indirect hydrological parameter estimation and direct estimation of hydrological variables [7]. Many applications in water resources and environmental monitoring require frequent coverage of the same area. With the availability of large volumes of remotely sensed data from multiple sensors, the application of remote sensing to water resources and environment has been increasing in recent years. The state-of-art satellite sensors are widely used in environmental applications, natural resources monitoring and management. The data from multiple sensors are acquired in multiple resolution (spatial, spectral, radiometric), multiple bandwidth and in varying conditions, they need to be harmonized and synthesized before being used [8]. 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. Remote sensing provides a platform for monitoring and modeling of seasonal suspended sediment distribution patterns, which is not possible though traditional measurement campaign. The rate of scattering and backscattering from water body is a function of size, texture characteristics of the suspended sediments and is strongly affected by other optically active water components. The prime objective of present research is to monitor the distribution of suspended sediments in the river waters and to elucidate the potential of remote sensing for monitoring suspended sediments.

Soil erosion and Sedimentation: Soil erosion impedes the sustainability of both land and water resources. Soil erosion is a three phase process consisting of:

- Detachment of individual particles from the soil mass. Rainfall impact of the soil is the most important detaching agent.
- Transport by erosive agents such as running water and wind. The river water caries large amount of suspended sediments brought by the feeding streams.
- When the water velocity is low a third phase, deposition occurs. The horizontal and vertical distribution of suspended sediments depends upon that of the particle size, shape, texture and density.

Sediment movement in rivers and reservoirs mainly depends on water flow and sediment characteristics. In a reservoir, there are two main patterns of flow motion: backwater flow and quasi-uniform flow. Under the condition of backwater flow, the water depth increases longitudinally and the flow velocity decrease accordingly. Sediment transport may have two patterns. One is sediment transport under open channel flow, where sediment particles diffuse to the whole section. As the flow velocity decreases longitudinally, deposition takes

Table 1: Land area affected by soil erosion by water and wind in South Asia

Country	Water Erosion (Mha)	Wind Erosion (Mha)	Total land Area (Mha)
India	32.8	10.8	328.8
Iran	26.4	35.4	165.3
Pakistan	7.2	10.7	79.6
Afghanistan	11.2	2.1	65.3
Nepal	1.6	0	14.7
Bangladesh	1.5	0	14.4
Sri Lanka	1.0	0	6.6
Bhutan	0.04	0	4.7
Total	81.74	59.0	679.4

Source: [10]

Table 2: Sediment data of World Rivers

River/Country	Catchment Area (1000*km^2)	Annual Runoff (km^3)	Annual Sediment load (Million Tons)	Average Sediment Concentration (kg/m^3)
Yellow/China	752.4	42.6	1,600	37.5
Ganges/India, Bangladesh	955	344	1,451	3.91
Bramaputra/ Bangladesh	666	384	726	1.89
Yangtze/China	1700	934	490	0.52
Indus/Pakistan	969	175	470	2.68
Amazon/USA	5770	5710	363	0.06
Irrawady/Burma	430	427	299	0.70
Missouri/USA	1370	616	218	3.54

Source: WAPDA, [12]

place. Such a kind of deposition is called back water deposition. The other is sediment transport by density current, which is formed by heavy sediment load with fine particles and moves along the natural rivers. When the incoming sediment load is different from the sediment transport capacity of the flow, longitudinal deposition or erosion will occur [9].

Sediments, which fill lakes, reservoirs and dams, are one of the most important environmental problems throughout the world (Table 2). The rivers of Pakistan carry much sediment either as bed load or in suspension. Sedimentation in the three major reservoirs-Tarbela, Mangla and Chashma in Pakistan is going to deplete their storage capacities by over 25% by the end of the year 2010 [11].

Study Area: The Tarbela Dam is the largest earth and rockfill dam of the world across the river Indus in Pakistan. The total length of the Indus is about 2,900 km.

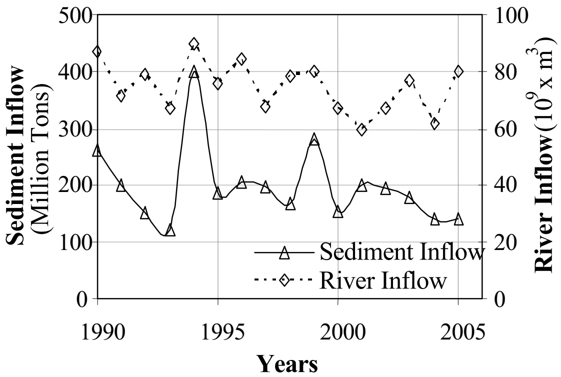


Fig. 1: Annual sediment load computed from hydrograph survey

The catchment area of the Indus River is 969000 km^2 with an annual runoff of 175 billion m^3 and annual sediment load of 470 million tons. Above Tarbela the catchment area is 169,650 km^2 with annual sediment load of 287 tons. Although the catchment area above Tarbela Dam accounts for only 17.5 percent of the total catchment area of the Indus, the annual sediment load above Tarbela accounts for 66 percent of the total sediment load of the river. The Indus River is one of the largest sediment producing rivers in the world. The main source of sediment is from the glacial landscape and erosion from steep sided barren slopes.

Melting glaciers and falling rocks leave behind large quantity of sediments each year. The climatic change impact has also jeopardized the situation. The change in river discharge, extreme events, change in land cover and rapid melting of glaciers are major cause of excessive soil erosion in the upstream areas. The sediment load varies with discharge, seasonal differences and conditions of the watershed and river morphology. The river basin and catchment areas have significant effect on the grain size distribution of the suspended sediments. The length of Tarbela dam reservoir is 97 km with an area of 260 km^2. Tarbela dam plays vital role in the national economy of Pakistan and its normal operation is imperative for the country. The large amount of sediment load carried by the Indus has shown a great threat to the dam due to serious sediment sedimentation in the reservoir. Heavy sediment load brought by the Indus River and its tributaries is major problem in the study area.

The sediment monitoring station is located 67 km upstream of the dam body. However, there is dire need to adopt methodology for effective and efficient monitoring of suspended sediments along the river reach on seasonal bases and during the flood to estimate the sediments distribution in the river.

MATERIAL AND METHODS

Laboratory Analysis: In order to investigate the effect of different concentration of suspended sediments on reflectance signals, experiment was performed in the laboratory. The spectral reflectance of collected soil samples from research study area with varying concentration of SSC were investigated in detail. The suspended sediment concentration data of the Indus River at the monitoring station on the day of satellite overpass was obtained from Water and Power Development Authority (WAPDA), Pakistan. The experiment was performed in the laboratory under controlled conditions and the depth of water column was kept constant at 40 cm. The spectral reflectance of water with varying concentration of suspended sediments (0 to 1000mg/l) was collected by means of a hyperspectral Field SpecPro FR Spectroradiometer (Analytical Devices, Inc., Boulder, CO).

It was observed that the reflectance increase with the increase in suspended sediments concentration and the peak reflectance shifts towards longer wavelength. Moreover, the increase in reflectance pattern was systematic through the entire range of spectrum. To investigate the field application of collected hyperspectral reflectance, the acquired lab reflectance with varying concentration of suspended sediments was integrated to ALOS/AVNIR-2 band widths. The regression model was developed between the simulated ALOS data and SSC. It was observed that a good correlation exists between the simulated data and SSC. The combination of ALOS/ AVNIR-2 bands 3 and 4 was selected to demonstrate the relationship between reflectance and suspended sediment concentration because SSC is strongly correlated with red and NIR domain. The developed reflectance model $(B_4+B_3)/\ (B_3/B_4)$ derived from series of laboratory experiments is the best predictor of SSC. The subscripts 4 and 3 represent band 4 and band 3 of ALOS optical sensor AVNIR-2.

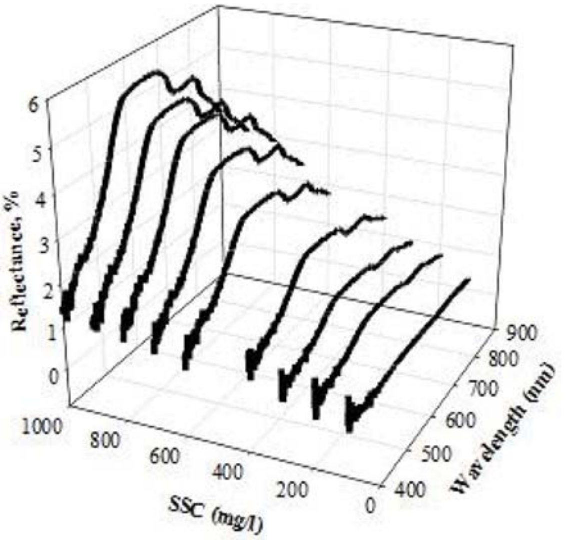


Fig. 2: Spectral reflectance of water with varying concentration of collected soil sample

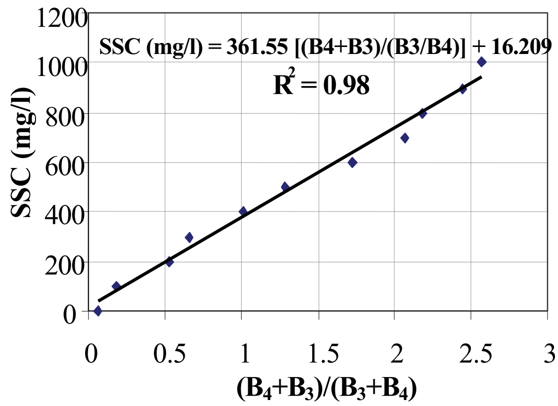


Fig. 3: Relationship between SSC and developed reflectance model

Application of Multispectral Remotely Sensed Data for SSC Estimation: Satellite and airborne optical sensors can provide the high spatial and temporal resolution data that is considered as a potential tool for monitoring and modeling inland and coastal waters. Satellite-based remote sensing provides one option for relatively low-cost assessment of suspended sediment concentration in surface waters [13]. In larger river like Indus River, Pakistan, the in situ measurements of suspended sediments can provide valuable data at discrete points. However, the logistics and expense of traditional data collection methods can rarely produce the synoptic coverage, resolution and temporal detail necessary to delineate the water bodies. One solution of this problem can be remotely sensed data. The satellites can provide repetitive and synoptic coverage. Remotely sensed images provide regional coverage with the potential for monthly to daily coverage.

ALOS Sensors/products: The Advanced Land Observing Satellite (ALOS) was launch on 26 January 2006. The Advanced Land Observing Satellite (ALOS) has two optical sensors called: Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) for digital elevation mapping and Advanced Visible and Near

Infrared Radiometer type 2 (AVNIR-2) for precise land coverage observation. The third sensor called L-band Synthetic Aperture Radar (PALSAR) for day-and-night and all-weather land observation. The Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) is a visible and near infrared radiometer for monitoring regional environment (land, coastal zones and water bodies etc.). The wavelengths covered by the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) include: Band 1 (0.42-0.50 µm), Band 2 (0.52-0.60 µm), Band 3 (0.61-0.69 µm) and Band 4 (0.76-0.89 µm). Three ALOS images acquired on 6 October, 2006 were analyzed in this research study. These images encompass the Indus River, Tarbela Dam and surrounding area in the Pakistan. The month of October is the end of the high discharge and flood period in the Indus River. For each band the image digital numbers (DN) were converted to top of atmosphere (TOA) spectral radiance (L) by using the following equation.

$$L = DN^{*} a + b \quad (1)$$

Where L is radiance ($Wm^{-2}Sr^{-1}\mu m^{-1}$), "a" is gain and "b" is offset. The vale of a and b can be retrieved from the scene header file. The TOA spectral radiance is converted into TOA reflectance for each band by using the following equation [14].

$$R(i) = \frac{\pi L(i)}{\mu_s E_s(i)} \quad (2)$$

Where:
i = 1,2,3 and 4; $\mu_s = \cos(\theta)$, θ is the solar zenith angle, E_s ($Wm^{-2}\mu m$) is the solar TOA irradiance. The solar spectral irradiance values are not provides with the product. It can be computed as proposed by Thuillier [15]. The TOA solar irradiance for the band 1,2,3 and 4 is 1943.3, 1813.7, 1562.3 and 1076.5 $Wm^{-2}\mu m^{-1}$ respectively. The TOA measurements are then corrected for atmospheric effects.

The atmospheric correction is the process of retrieving the surface radiance and surface reflectance from the satellite radiances. The dark pixel subtraction technique was used to remove or reduces the atmospheric influence on water-leaving light signals. A darkest pixel subtraction approach is simple and feasible and may apply when no ground truth data corresponding with the image is available. Hadjimitsis *et al*. [16] reported that, from an operational point of view, the darkest pixel approach was preferred over more sophisticated techniques that require atmospheric and meteorological

Fig. 4: ALOS/AVNIR-2 Image of Tarbela Dam and Indus River, Pakistan. Acquisition Date: October 10, 2006

data. The dark pixel subtraction is based on the assumption that an effective black body exists in the image, resulting in a pixel value of zero [17]. The minimum pixel value for that point in each band is because of atmosphere and subtracted from the corresponding band. In the upstream area of the Indus River small isolated clean water pond located in the mountains with the minimum pixel values was considered for the purpose of atmospheric correction. The resultant reflectance is the derived reflectance at the surface and it is atmospherically corrected. The reflectance value at the dam and along the river reach was computed for the bands 1, 2, 3 and 4 of AVNIR-2 sensor. It was observed that the reflectance value along the river reach vary from point to point and strongly depends on the amount of suspended sediment concentration.

ASTER Sensor/product: The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor resides on the Terra platform, which was launched in December 1999. The ASTER consists of three sensors: the Visible and Near-infrared (VNIR) sensor which has three bands with 15m spatial resolution including backward telescope for stereo, the Shortwave Infrared

(SWIR) sensor havinf six bands with 30m spatial resolution and the Thermal Infrared (TIR) with five bands with 90m spatial resolution. The coordinate system of the ASTER scenes is UTM 43N and their datum is WGS84. The Level 2 surface reflectance data set is obtained by applying an atmospheric correction to radiances collected by the ASTER sensor. The atmospheric correction algorithm used to retrieve the surface reflectance relies on a look-up table (LUT) approach. The atmospheric conditions are defined by the aerosol size distribution (or equivalently the aerosol type), the aerosol amount, surface pressure and the sun-satellite geometry. The atmospheric correction removes effects due to changes in satellite-sun geometry and atmospheric conditions. The atmospheric correction algorithm is applied to clear-sky pixels only and the results are reported as a number between 0 and 1 [18].

Optical Model Inversion Techniques: To develop the monitoring system by means of remote sensing, the collection of appropriate ancillary field data sets is as important as the remotely sensed data. The in situ suspended sediment concentration at the monitoring station was 255 mg/l (sand 20%, silt 55% and clay 15%). However the SSC at other different location was unknown. In order to deal with lack of data problem, one approach is to develop relationship between SSC and reflectance in the laboratory and apply that model on the image to quantify the SSC along the river. However the lab conditions vary significantly from the field conditions. The applicability of the laboratory developed model on the image may lead to inaccurate estimation of the suspended sediments. In such situations only the remote sensing application provides solution to engineers and resource managers. To quantify the SSC, the model inversion technique was adopted. The spectral reflectance curve was computed with collected or assumed water quality data. The computed spectral curve was integrated into band widths of ALOS/ASTER sensor. The simulated model bands were compared with ALOS/ASTER spectral signals of the same sampling station. The procedure consists in minimizing the difference between modeled reflectance data and multispectral reflectance data. At different locations, along the river, the difference between the modeled and multispectral reflectance data was minimized by varying SSC and the amount of suspended sediment was estimated. The basic concept is to consider ALOS-AVNIR-2/ASTER-VNIR reflectance values as the true values and minimize the difference between modeled and multispectral data by changing the suspended sediment concentration.

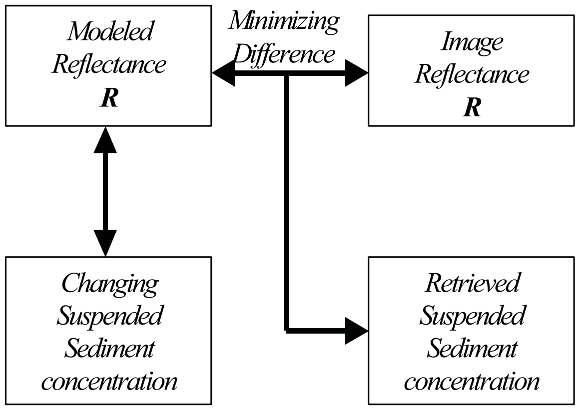


Fig. 5: Concept diagram of model inversion technique

Spectral Reflectance Model: Mobley, [19] was prescient in stating that the development of remote sensing inversion algorithms for use in case - 2 waters scarcely has begun. As with other facts of the hydrologic optics of such waters, the remote sensing of case 2 waters will provide challenging research problems for a generation of scientists. In an effort to deal with case 2 turbid water, the remote sensing spectra were modeled.

The relationship between reflectance *R*, inherent optical properties (IOPs) of the medium, absorption coefficient a (λ) and backscattering coefficient $b_b(\lambda)$ is expressed as described by Morel, [20];

$$Rrs(\lambda) = \frac{f}{Q} \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)} \quad (3)$$

Where:

f is a coefficient and the commonly adopted value of *f* is 0.33, which is valid for zenith sun and for large variety of natural waters, the value of factor Q (ratio of upwelling irradiance to upwelling radiance) is ~ 3.4 [21]. For many studies, Q is often arbitrarily chosen as a spectral constant. However, Carder *et al.* [22] found that Q is not spectrally constant for the 1990 stations and there was a trend for Q to increase with wavelength (an inverse trend compared with b_{bs}). The value of 3.14 is used for analysis. In the research study area during the flood season (June-October), the suspended matters in the river water are mainly composed of inorganic sediments. The presence of chlorophyll in the water is neglected. For further analysis, the absorption and scattering by chlorophyll is not taken in to account. The absorption coefficient a(λ) and backscattering coefficient $b_b(\lambda)$ is written as follow;

$$a(\lambda) = a_w(\lambda) + a_y(\lambda) + a_s(\lambda) \quad (4)$$
$$b_b(\lambda) = b_{bw}(\lambda) + b_{bs}(\lambda)$$

Where:

the subscript w, y and s represents water, colored dissolved organic mater and total suspended sediments.

The value of a_w and b_{bw} are taken from Smith, [23] for the range 400-800 nm and are deduced from Hale and Query, [24] for the range 800-900 nm [25]. a_y is modeled as follow [26]; $a_y(\lambda) = a_y(\lambda_o)\exp[-S(\lambda-\lambda_o)]$, where λ_o is 400 nm. Mobley, [19] have mentioned different values for colour dissolved organic matters in coastal and estuarine waters. The average value of 0.3 m^{-1} for the river is adopted and kept constant along the river reach as mentioned; $a_y(\lambda_o)$ =0.3 m^{-1} and S=0.014 m^{-1}. Absorption by sediment is modeled as [27]: $a_s(\lambda) = k_1 C_s^{k2}(\lambda^{ref}/\lambda)$. k_1 and k_2 are optimization parameters for tripton with values of 0.32-0.55 and 1.04-1.22 respectively and for detritus the value of k_1 range from 0.016-0.025. λ_0 is the reference wavelength and taken as 400nm. In this analysis the value of k_1 and k_2 are taken as 0.05 and 1.1 respectively and C_s is suspended sediment concentration (mg/l).

Light scattered by suspended sediment is modeled using the Mie theory. $b_{bs}(\lambda)$ is written as [25];

$$b_{bs} = \frac{3C}{2\rho} \cdot \frac{1}{ln(D_2/D_1)} \int_{D1}^{D2} Q_{bb} . D^{-2} dD \quad (5)$$

Where:

C is suspended sediment concentration, ρ is the sediment density = 2600 kg/m^3. Q_{bb} is the backscattering efficiency factor of the suspended particle of refractive index m_r. the refractive index of sediment is taken as 1.125. D_2 and D_1 represents maximum and minimum diameter of the suspended particles (200 - 0.01 µm), which include variety of suspended particles. The developed modeled reflectance spectra is simulated to ALOS/AVNIR-2 band widths and compared with AVNIR-2 data for the purpose of SSC estimation. The framework for development of model for estimation of suspended sediment concentration by using remotely sensed data is illustrated in Figure 6.

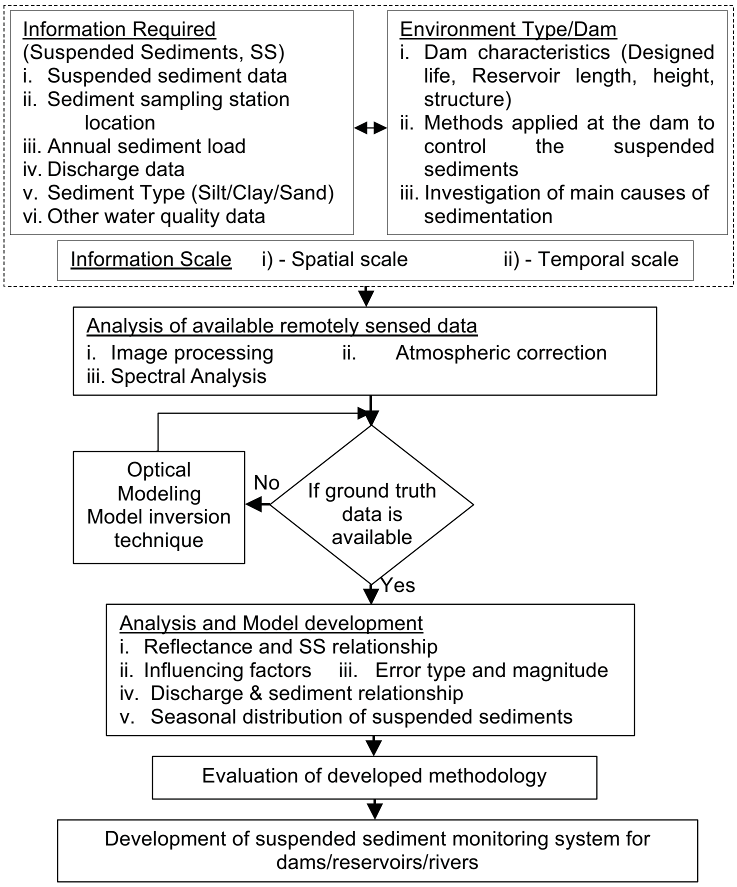


Fig. 6: Frame work for development of suspended sediment estimation model by means of remote sensing

RESULT AND DISCUSSION

The suspended sediment concentration (SSC, 250 mg/l) at the monitoring station located upstream of the dam body is known. To evaluate the developed model and methodology, with the suspended sediment concentration of 250 mg/l, the modeled spectra was developed and simulated into AVNIR-2 band widths. The simulated modeled reflectance data and AVNIR-2 reflectance data at the same sampling point was compared as depicted in Figure 7. It was observed that the difference between the two reflectance values (Modeled and ALOS/AVNIR-2) was minimal in the green, red and NIR domain and overall showed well agreement. The difference in blue band (Band 1) is significant and may minimize by considering absorption and scattering by Chlorophyll-a present in the water. It proves that the proposed approach is applicable for estimation of suspended sediments in turbid water bodies and amount of suspended sediments can be estimated.

The input suspended sediment concentration at other points are assumed or estimated by lab based model and a modeled reflectance spectrum was generated. The developed spectrums were simulated to the same band widths of AVNIR-2 sensors. By varying the value of input suspended sediment concentration the difference between the modeled and ALOS/AVNIR-2 reflectance value was minimized. The output value with minimum difference in the red and NIR domain is the suspended sediment concentration at the point. By adopting the same approach, the suspended sediment concentration along the river at every 10 km was retrieved. It is evident from the graphical presentation that the SSC vary along the river and the peak was observed at about 70 km upstream of the dam. In the range from 60km to 90km upstream of the dam, the amount of suspended sediments is significant and tends to decrease towards dam body. The velocity of the river inflow containing sediments decreases upon entering Tarbela reservoir, which reduces the sediment carrying capacity of the river water.

To estimate the yearly and seasonally distribution of SSC, ASTER-VNIR scenes of Indus River, Pakistan acquired on 07-06-02, 07-04-15 and 05-06-12 were analyzed. By opting the same model inversion technique, as described for AVNIR-2 sensor, was adopted. The suspended sediment concentration along the river reach was computed by minimizing the difference between modeled and ASTER/VNIR sensor data.

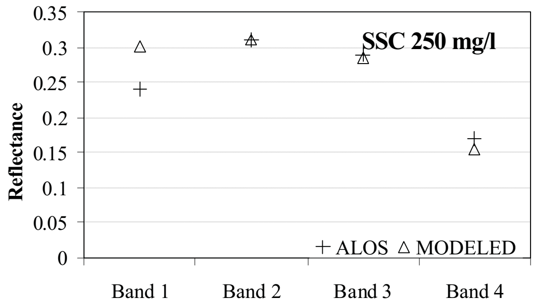


Fig. 7: Comparison of modeled and ALOS/AVNIR reflectance data

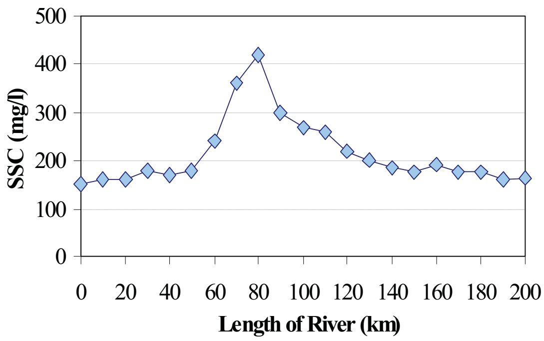


Fig. 8: SSC along the river reach

The developed remote sensing methodology enables retrospective analysis of the AVNIR-2 sensor data and ASTER data of Indus River, Pakistan. The coarse sediment tends to deposit in the upper reaches of the reservoir, while the finer particles travel downstream towards the dam. The graphical demonstration of suspended sediment distribution reveals that heavy sediment load is settling upstream of the dam in the range from 60 km to 90 km, thus reducing the storage capacity of the dam. The periodic examination of the sediment deposits and distribution in the upstream and downstream of the dam is vital to enhance the mitigation efforts for reduction of sediments. The contribution of sediment load is significant from the upstream catchment area. Integrated water resources management in an organized and coordinated manner is the solution to deal with management activities in the upstream area. By adopting the proposed methodology, the satellites archives may become a valuable resource for water resources engineers and researchers to remotely monitor the water bodies in the absence of ground truth data. The proposed methodology is considered not to be susceptible to the lack of ground truth data and weather conditions.

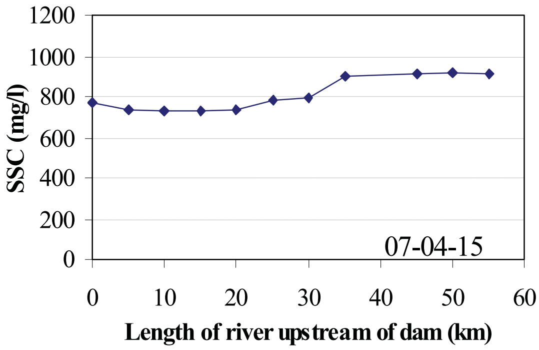
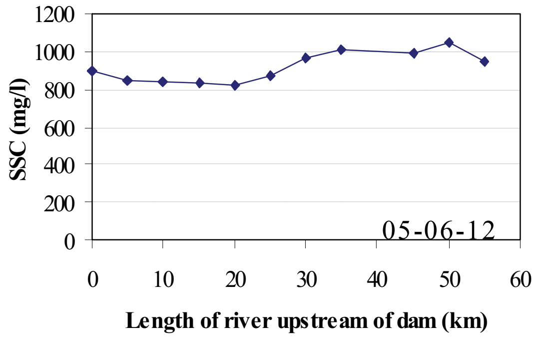


Fig. 9: SSC along the river reach



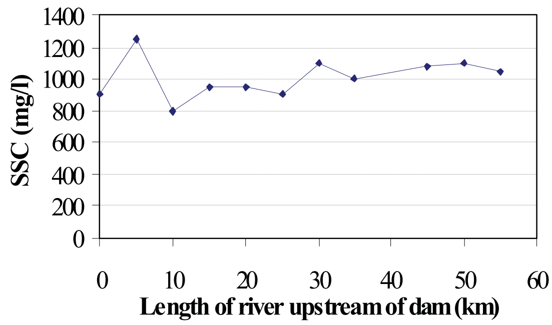


Fig. 10: SSC along the river reach during flood season

Based on the develop methodology, the satellite sensor data can become an independent measurement tool and the lack of sophisticated concurrent ground truth observations will not hamper the monitoring and modeling the water bodies.

SSC Model Development: For the purpose of this study, the combination of ALOS/ AVNIR-2 bands 3 and 4 and ASTER/VNIR sensor band 2 and Band 3N was selected to demonstrate the relationship between reflectance and suspended sediment concentration because SSC is strongly correlated with red and NIR domain.

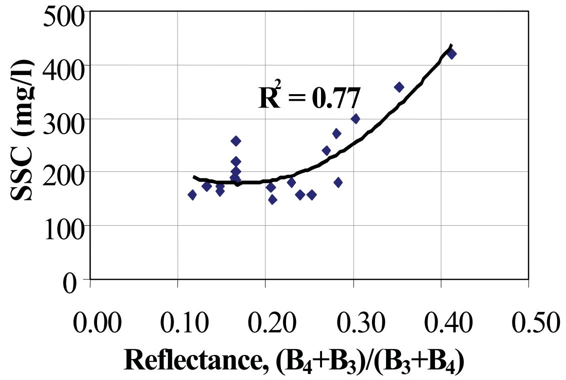


Fig. 11: Relationship between SSC (mg/l) and reflectance

The developed ALOS/AVNIR-2 reflectance model (2 band Model) $(B\lambda_4+B\lambda_3)/(B\lambda_3/B\lambda_4)$ derived from series of experiments is considered to be the best predictor of SSC. The subscripts 4 and 3 represent band 4 and band 3 of ALOS optical sensor AVNIR-2. The term $(B\lambda_4+B\lambda_3)$ represents 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 chlorophyll-a concentration on red domain (Band 3) is well documented in literature. The term of $(B\lambda_3/B\lambda_4)$ reduce the chlorophyll interference to the low suspended sediment concentration. Regression model was developed in order to quantify the suspended sediment along the Indus River. As depicted in the figure 11, the correlation coefficient of 0.77 was obtained by applying the combination of two band model approach. It is concluded that the ratio of AVNIR-2 Band 3 and Band 4 by applying 2 band model approach is the best predictor of SSC. The developed model for estimation of suspended sediment concentration (SSC) is of the following form;

$$SSC(mg/l)=m\left[(B_4+B_3)/(B_3/B_4)\right]^2-n\left[(B_4+B_3)/(B_3/B_4)\right]+l$$

Where:

m, n and *l* are coefficient with values 4403, 1492 and 305 respectively.

The SSC for the ASTER image acquired on 07/06/02 and 05/06/12 represents high concentration of suspended sediments. The month of June is considered as flood season and river water carry heavy sediments load. To develop the model for estimation of suspended sediments by using ASTER/VNIR data, the 2 band regression model was developed. The relationship is illustrated in Figure 12.

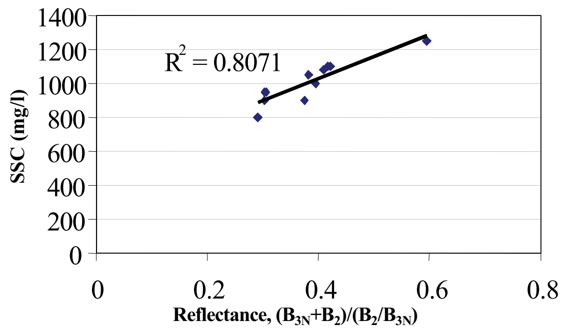


Fig. 12: Relationship between SSC (mg/l) and reflectance

As obvious from the graph, the correlation coefficient is high. The regression model is of the following form;

$$SSC(mg/l)=m\left[(B_{3N}+B_2)/(B_2/B_{3N})\right]+n$$

Where:
the value of coefficient *m* is 1291 and *n* is 514.

CONCLUSION

Remotely sensed data and techniques enhance the efficiency and reliability of the data, as well as complement traditional data collection techniques. Remote sensing has many actual and potential applications for water resources and environmental monitoring and management. The inversion technique is feasible to cope with lack of ground truth data problem. The integration of satellite data, in situ data and optical model is an effective and efficient tool for monitoring erosion, deposition areas and sediment distribution in water bodies. The proposed methodology is effective and efficient to deal with sediment management in large rivers. The ratio of ALOS/AVNIR-2 Band 4 and Band 3 (2 Band Model) and ASTER Band 2 and Band 3N was the best predictor of SSC. In developing countries the ground truth data is often minimal or unavailable. It is difficult for resource managers to plan strategy to cope with sedimentation and erosion problems. The usefulness of the research is to make possible to work with minimum data with high reliability and efficiently. In this reach work the concerned parameters was suspended sediments. If the concentration of one water quality parameter is known, the concentration of other parameters on the same sampling point may estimated by applying the same methodology. The research has shown the feasibility of multispectral data to estimate the suspended sediments in the surface water of rivers and reservoirs. To cope with sediments and soil erosion, it is imperative to incorporate sediment assessment as an integral part of water resources and environmental planning, development and management. Without this approach the problems of the water and environmental sector are going to compound in the future.

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