LECTURE-6

Application of Remote Sensing in Sedimentation Studies of Lakes and Reservoirs

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INTRODUCTION

Sediment load in reservoir is an important environmental parameter used in determining water quality (Kook and Cheng 1978). A variety of factors such as basin geology, hypsography, soils, and chemical reactivity, hydrology and land use pattern regulate the sediment load of river systems (Garret et al1975).

Conventional methods for the measurement of suspended load and pollutants in-site and in the laboratory are expensive compared to remotely sensed data. Satellite borne sensors have the capabilities of providing repetitive, low cost multispectral coverage over wide areas and have the potential to monitor the water quality (Mertes et al., 1993).

The absorption and scattering properties of sediment type affect water reflectance (Novo et al 1989). The suspended sediment concentration and reflectance relationship depends on many factors including physical and optical properties of sediment type (Hoyler 1978, Chen et al 1991, Choubey, 1994).

The successful approach to quantitative estimation involves statistical correlation with field measurements obtained simultaneously with satellite overpass. Recently several linear models have been developed (Rimmer et al 1987., Ritchie and Cooper 1988., Albanakis 1990., Choubey 1998). Munday and Alfoldi (1979, suggested a nonlinear model. However the models developed by investigators did not fully account for spatio-temporal variation in the type, size and concentration of the sediment. These studies of the relationship between water quality parameter and remotely sensed observations, have generally lacked a sound field measurement for the statistical relation.

Considering of comprehensive and accurate field observation would permit the development of single set of suspended solids predictive regression equation from concurrent field and satellite observations collected on multiple dates.

METHODOLOGY

For the evaluation of ground truth and their correlation with Indian Remote Sensing Satellite-1A digital data, a small reservoir (Tawa) in the Narmada basin in Central India was chosen.

(A) FIELD SURVEY

Ground truth requirement for water quality survey are different from those of land survey as a result of dynamic nature of aquatic environment and complex energy water interaction leading to spectral contamination of remote signals by noise component.

Selection of sampling sites

The range lines erected by Directorate of Irrigation and Research, Govt. of Madhya Pradesh, India, were used for fixing the sampling locations in the reservoir (Fig. 1). The range points were fixed above full reservoir level (1166 ft.) at a interval of 3/4 kms., on all the tributaries joining the reservoir at various reaches. Out of the total 141 ranges, 47 ranges have been chosen for stretch of the water spread. The sampling sites were fixed on the range line, in such a way that all the tributaries joining the reservoir are covered. Adequate care has been taken to ensure that each site represent 3x3 pixel block, eliminating the possible shoreline effect on signals.

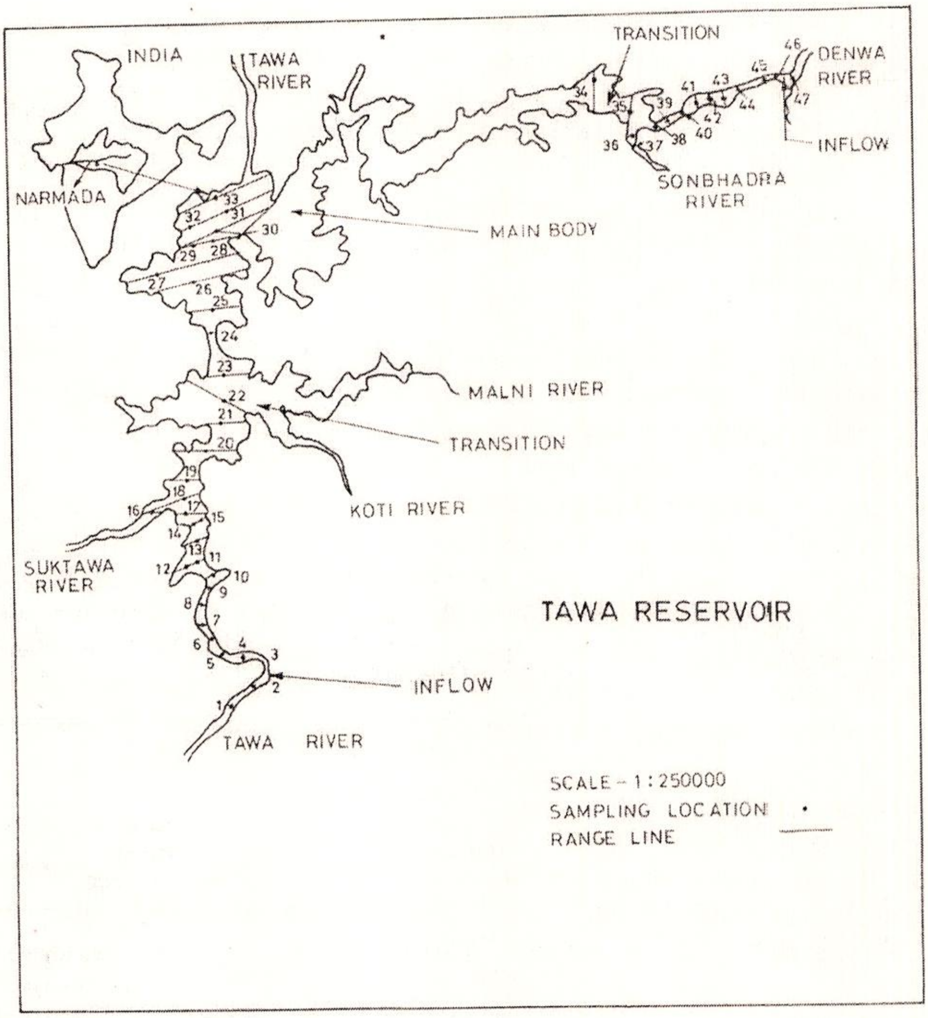


Fig. 1. Location map of water sample sites on Tawa reservoir

i) Time of sampling

The amount of sediment load changes rapidly with inflow, hence water samples should be taken as close to the time of satellite overpass as possible. In order to reduce the time leg between IRS overpass and sampling, the sampling was carried out between 7 am to 6 pm on the day of overpass i.e., October20, 1988 to conduct field measurements and collection of water sample at all the 47 sampling sites.

ii) Depth of sampling

In order to avoid bottom reflectance and to measure the light penetration depth at sample points, secchi disc was used. An aluminium disc of 20 cms diameter was used with additional iron pallets attached to make it heavy and steady in the water during light penetration depth measurements. The average of two reading for the depth at which the disc disappears during descending and reappears during lifting was adopted. At light penetration depth, water samples were collected with the help of fabricated depth sampler (weight 5 Kg) similar to Punjab type bottle sampler.

iii) Bottom effect

The bottom effect was avoided by selecting sampling points with minimum 4 feet depth. At every sampling point to avoid bottom noise, secchi disc depth and total depth was measured for identifying point with negligible bottom effect.

iv) Water color

The reservoir surface water color was observed through viewing tube and then compared the hue with Munsell standards (Munsell Soil Color Charts, 1975).

A field trip was conducted to Tawa reservoir on day of Indian Remote Sensing satellite overpass. The reservoir was sampled by motor boat all along the reservoir on predetermined sampling locations (Fig.1). Secchi disc depth, pH, electrical conductivity, turbidity measurements were taken with the help of secchi disc, portable pH-Conductivity meter model CONSORT C425, and Turbidometer (model HACH 2100 A) respectively, for all the 47 sampling locations. The water samples were immediately taken to the laboratory for further analysis.

(B) LABORATORY ANALYSIS:

Water samples were filtered through membrane filters to estimate the total suspended matter. Suspended sediments of five water samples representing various reaches of the reservoir were selected for bulk mineralogy. The mineral compositions were determined using a Philips X ray diffractometer with Cu-Kα radiation with a Ni filter.

Thirteen water samples representing various reaches of the reservoir were chosen for the particulate grain size analysis. The size analysis of suspended sediments for reservoir water was done by laser FRITSCH PARTICLE SIZER (model ANALYSETTE -22).

(C) SATELLITE DATA:

IRS-1A-LISS-I geometrically corrected computer compatible tapes (CCT) for the study area path-row, 27-52 were acquired. IRS-1A-LISS-I digital data was in four spectral bands with spatial resolution of 72.5 metres. The time of overpass was 10.25 AM (IST). The details of the LISS-I bands and their wavelength range are given below: (IRS data user hand book 1986). Digital data for each spectral band were extracted for 3X3 array encompassing each 47 sampling locations. The mean radiance values were calculated for the pixel of each array for all the four bands.

RESULTS AND DISCUSSIONS

Spectral response in Tawa reservoir water spread area shows maximum radiance values in the inflow zones and decrease toward transition zone and the main body of the reservoir. However Denwa flank of the reservoir shows higher response value than Tawa due to variation in grain size and mineral composition. The mixed effect of sediment load from both rivers was observed in the main body of the reservoir. Here illite and montmorillonite, feldspar, carbonate percentage are significantly high which are mainly contributed by Denwa river. This may be a reason for the higher spectral radiance values in the main body of reservoir and to some extent to inflow of sediment load from rivers joining the main body.

The mean radiance values of each LISS-I band individually and in combination was correlated with suspended solids concentration. In this analysis the relationship between October 20, 1988 LISS-I mean radiance values and measured values of SSC were quantified using regression techniques. An optimum equation was chosen based on higher coefficient of determination and lowest standard error for suspended solids. The best fit linear equation and multiple regression equation for estimating the concentration of suspended solids in water of Tawa reservoir are given in Table 1(a) and (b).

The reflected solar radiation from water surface changes with the amount of suspended solids and wavelength. The lower wavelength range 0.45 to 0.59 um (band 1 and 2) does not show linearity with suspended solids beyond 40 ppm. However as the concentration increased the response value also increased. As the wavelength range advanced from 0.45 to 0.68 um, the change in response value with change in suspended solids concentration exhibited increasing trend.

A comparison of SSC estimated using the equation with field measured value showed that estimated value were high at low concentration and low at high concentration (Fig. 2). The graph of estimated versus measured values also shows that generally the values are scattered around 1 : 1 line. The analysis of Table 1(a) shows that band 3 radiance values has high coefficient of Determination (r=0.87) and lowest standard error 1.3ppm for SSC.

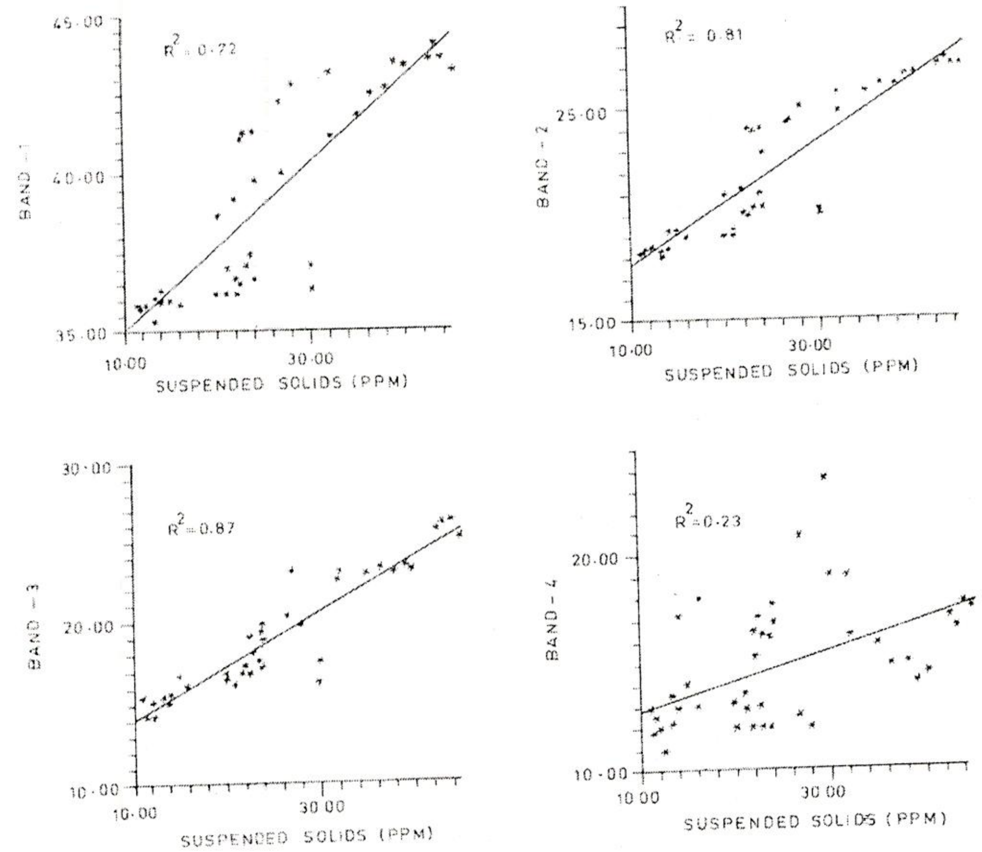


Fig. 2. Relation between suspended solids concentration and LISS-I mean pixel values in all the four bands

Table 1(a). Best fit linear equations used to estimate values of suspended solids concentration from October 20, 1988, LISS-I mean radiance values.

	Coefficient of determination	RMSE
Yss = 6.81+ 0.73 x B1	0.73	1.62
Yss = 4.81+ 0.81 x B2	0.81	1.40
Yss = 3.33+ 0.87 x B3	0.87	1.29

Where Yss = are the estimated values of the suspended solids concentration (ppm).

B1, B2, B3 = are the mean radiance values of Band 1, Band 2 and Band 3 respectively.

All the combination of the four LISS-I bands were made using mean radiance values. None of the band combination using linear regression techniques had a better coefficient of determination with the SSC except LISS-I band 3 mean radiance values. Therefore in order to increase the analytical range a multiband approach has been adopted.

Initially all the four bands were used for estimating SSC in simple regression analysis. There was a strong correlation among the band 1,2 and 3 and a very poor correlation of band 4 with other bands. Hence band 4 was omitted and the three bands (band 1,2 & 3) were tested in combination.

A three bands 1, 2 and 3 combination was selected in multiple regression analysis to represent the best statistical relationship between the suspended solids measured from October 20, 1988 water samples and corresponding mean radiance values. In these the dependent variable were measured values of suspended solids,and the LISS-I three bands digital data were independent (estimators) variable of 47 sample sites.

Regression equation and statistical parameters were computed for all possible band combinations in regression. Based on the highest coefficient of determination, the F value (4 time greater than critical value of F (Fcr) and minimum standard error of the estimates, the regression equations were chosen.

The regression equations to represent best relationship between the measured suspended solids concentration, and mean pixel value are given in Table 1(b). The relationship between measured and estimated values are shown in Fig. 3. The F values were statistically significant at the 0.01 level. The significant F value indicate that variation in spectral response account for variation in SSC.

Table 1(b). Multiple regression equation used to estimate values of suspended solids concentration from October 20, 1988, LISS-I mean radiance values.

$$Yss = -a - bX_1 + cX_2$$

Where Yss = Suspended solids concentration expressed in ppm

X_1 = (band 1 + 2 + 3)
X_2 = (band 1 + band 3)

a = - 61.80, b = - 0.94, c = 2.79

Coefficient of determination	0.84
Coefficient of Correlation	0.92
F value	108.75
R.M.S.E	3.99
F/Fcr (0.01 level)	20.99
Residual range	-6.24 to 10.93

It has been observed that estimated concentration values are over estimated by the equation may be due to higher concentration of suspended solids. A comparison between estimated suspended solids concentration and measured values shows that there is variation between the two data sets. This may be due to influence of concentration of suspended solids which dominate the reflectance grain size and mineralogy.

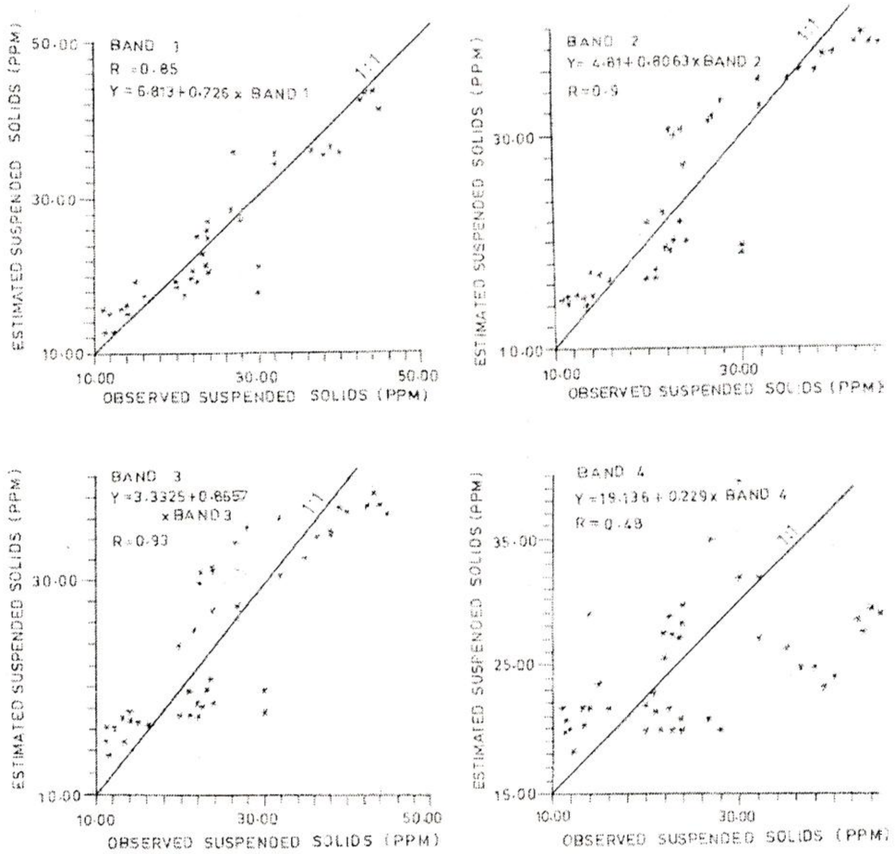
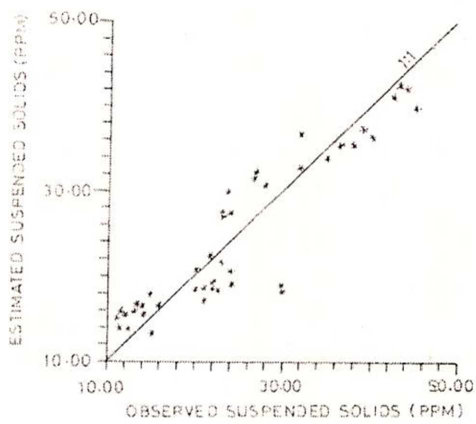


Fig. 3. Relation between field measured and estimated values of suspended solids drawn from a simple regression equation using 20 October 1988 LISS-I mean pixel values

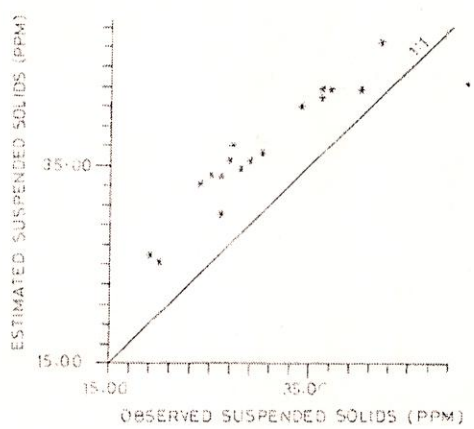
A large variation between measured and estimated concentration values may be due to coarse grained minerals. This variation is a function of difference in scattering properties of coarse and fine grained particles and mineral types.

The results of the regression analysis of estimated versus measured values of suspended solids showed that simple linear and multiple regression accounted for 85 per cent or more of variability. A comparison of field measured and estimated values from the equation for suspended solids (Fig. 4) indicates that estimated values were generally high at low concentrations and low at high concentrations. Similar finding is reported by Ritchie and Cooper (1988).

For verification of the multiple regression equation, Table 1(b) was applied to the 28 September 1988 LISS-I Bands 1, 2 and 3 mean pixel values for 21 sampling sites in order to estimate the concentration of suspended solids. Results obtained for the coefficient of determination of the standard error are given in Table 1(b). The relation between field measured values and values estimated by October equation (Fig. 4) show that all the September values lie above the 1:1 line, thus indicating that the October regression equation overestimates the suspended solids from the September observation, since uncalibrated LISS-I mean pixel values were used in this analysis and higher solar elevation and atmospheric effect have an effect on the September data (Yarger et al., 1973).



(*a*)



(*b*)

Fig. 4. (a) Relation between field measured and estimated values of suspended solids drawn from multiple regression equation using 20 October 1988 LISS-I mean pixel values. (b) Relation between field measured and estimated values of suspended solids drawn from multiple regression equation using 28 September 1988 LISS-I mean pixel values for equation verification.

The equations developed appear to be satisfactory for predictive purpose. This may not be an exhaustive validity test, since the data were from the same reservoir as that used to generate the equations. This indicates the LISS-I multi-spectral data could be effectively used if the sun angle and atmospheric effect in the data is removed, which would help in developing a single set of regression equations from concurrent in situ and LISS-I data collected on multiple dates (Verdin 1985).

CONCLUSION

The result of the calibration of IRS-1A-LISS-I spectral digital data to concentration suspended solids are encouraging. On the basin of results obtained from present study it can be concluded that :

(1) In the concentration range between 10-50 ppm, a positive relationship exist between concentration of suspended solids and visible wavelength band 1,2 and 3 (0.45 to 0.86 μm) ratio.

(2) IRS-1A-LISS-I spectral data can be effectively used to monitor sediment load in the reservoir water. Visible wavelength bands of LISS-I are more useful than near infrared band (band 4) especially band 3 (0.62-0.68 μm) for the quantification of SSC.

(3) The relationship between suspended solids concentration, grain size and mineral composition are the main factors, which causes variability between measured and estimated values of suspended solids.

(4) The selection of sampling sites on range line or with reference to cultural features help in transferring sampling site on image accurately.

(5) For the situation in which a substance is introduced into part of water body (such as effluent from minor tributaries, industry), a number of points both inside and outside the plume must be obtained to insure against false correlation as a result of non-homogeneity.

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