Application of Remote Sensing for the Assessment of Water Quality : A case study of Tawa Reservoir

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ABSTRACT

An attempt has been made to quantify the relationship between the variation in IRS-IALISS- I radiance data and field measured change in secchi disc depth. Secchi disc depth was measured for 47 predetermined sampling locations on reservoir surface water. At extinction depth (secchi depth), water samples were collected from all the sampling locations. Suspended sediments of eight locations representing various reaches of the reservoir were selected for mineralogical, particle size and optical properties analysis. The LISS-I radiance value in band 1 (0.45-0.52μm) band 2 (0-52-0.59 ìm) and band 3 (0.62-0.68 ìm) were used in a regression analysis. The coefficient of correlation between observed and estimated values was $r = 0.92$ for SD, indicating that the equation could accurately predict the water clarity (SD) for this reservoir on new occasions from IRS-IA-LISS-I spectral data. It is shown that mineral composition and optical properties of suspended sediments influence the reflected radiance of water quality. It is concluded that IRS-IA-LISS-I data provide a useful means of mapping water quality in reservoir.

INTRODUCTION

Water quality is an important environment variable, because it affects human health and economic activity (Alfoldi and Munday, 1978). Suspended sediment is an important environmental parameter used in determining water quality. Sediment deposition in reservoir reduces its storage capacity and, hence, its ability to control flooding. Suspended matter reduces the penetration of light into water, this further reducing the production of food for fish. The poor visibility in turbid water also makes it difficult for fish to find what food is available (McCauley, 1977).

Water quality in the form of the water transparency in the visual region is very important for hydro-optical application (Lindell *et ai.,* 1985). Absorption and scattering processes determine the water transparency. Light penetration depth is primarily controlled by sediment loads (Yarger *et el.,* 1973). Several investigators successfully used Landsat MSS/TM imagery in determining and monitoring water quality in reservoirs and estuarine systems. Some studies include Bukata *et at.* (1983), Khorram and Cheshire (1985), Ritchie and Cooper (1988), Lindell (1985), and Ramsay and Jensen (1990). These investigators used multispectral digital data and concurrently acquired field measurements to develop a predictive equation for water quality parameters. Such methods are specific by their very nature, site, and even season (Nanu and Robertson, 1990). However, there still exists a need to study physical and optical properties of suspended sediments to enhance the utility of remote sensing for water quality monitoring.

The purpose of this study was to quantify the relationship between remotely sensed data and water clarity. The effect of clay and non-clay minerals on water transparency with particular emphasis being given to the spectral complexities of the reservoir water were subject of this study. The IRS-IA-LISS-I multi-spectral digital data have been used in this study.

STUDY AREA

Tawa reservoir is a large impoundment located in Central India on the Tawa River of the Narmada basin (Figure 1). The water spread area is about 225 km^2 and filling of

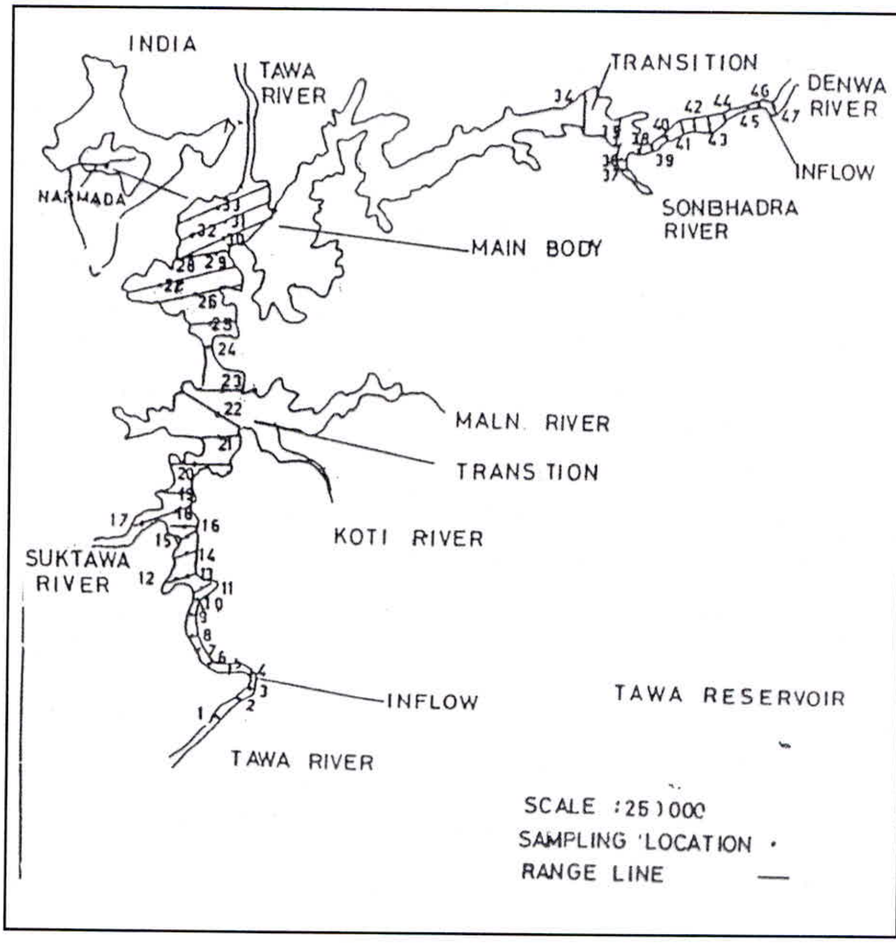

Fig 1. Location map of water sample sites on the Tawa reservoir

reservoir is mainly from two major rivers, the Tawa and Denwa, during the monsoon period. These rivers join the reservoir from the South and east and flow through different environments. The Tawa river flows through semi-forested and cultivated land, whereas the Denwa flows through dense forest. A very small portion of the area is a meandering plain formed due to the meandering of the Tawa River. Mostly rivers are structurally controlled and, hence, very deep bank sides occur. The principal tributaries of the Tawa River are the Machua, Malni, Suktawa, Koti, and Sonbhadra of Denwa river. The basin is characterised by a tropical climate with an average annual rainfall of 156 cm.

The soils are derived from sandstone and basalt under a subtropical monsoon climate. Folding and faulting have given rise to different features and physiography has modified the soil formation at different physiographic situations. About 83.8% of the area belongs to red and yellow soils of the catchment; out of this 57.3% is shared by coarse loamy and 26.5% by fine loamy soils. The dark grayish brown (black) clayey cracking soil occupies 14.1 % of the catchment area. The alluvial soils have a minor extent of 1.5%. The soil taxonomy is classified as orthents, ochrepts, ustalfs, and usterts, etc.

The Tawa and Denwa rivers drain an area of 231 0 km^2 and the catchment area is 5982.90 km^2. The reservoir is designed to have a storage capacity of 0.231 million ha m at full reservoir level of 355.397 m.

METHODOLOGY

The secchi disc was used to measure the extinction depth (the depth at which the disc just becomes invisible in the water). The average of two readings for the depth at which the disc disappears during descending and reappears during lifting is adopted. The concentration of suspended material is compared with the depth of penetration. Secchi depth observations were made from the shaded side of the boat to avoid sun glare (Davies, Colley and Vant, 1988) in all 47 sampling locations (Figure 1). At extinction depth, water samples were collected with the help of a depth sampler for all the sampling locations. At every sampling point the depth of the bed was measured for identifying a point with negligible bottom effect and to ensure the extinction depth is less than the bottom depth to avoid bottom noise effect.

Water samples were filtered through an ultra cellulose membrane filter paper (millipore 0.45 *ìm)* using a Buchner funnel and a vacuum pump to estimate the total suspended matter. Suspended sediments of eight water samples representing various reaches of the reservoir were selected for bulk mineralogy and particle size analysis. Initially, the suspended matter was treated with hydrogen peroxide to remove organic matter coatings on mineral grains. The sediments were mounted by the drop on slide technique (Gibbs, 1967) and were uniformly spread on the glass slide to avoid differential settling of the particles and glycolation. The mineral composition was determined using a Philips x-ray difractometer with Cu-Ká radiation and Ni filter. Mineral identification and estimation of abundance was done following the methods of Biscaye (1965) and

Carrol (1970).Particle-size distribution in suspended solids were determined by a Fritsch analysette-22 laser particle size analyser.

IRS-IA-LISS-I computer compatible tapes (CCT's) were acquired for the scene (path-row 27-52) of Tawa reservoir on 28 September and 20 October 1988. The image data on the CCT's were radiometrically and geometrically corrected. In order to seperate land and water components, a binary mask was made by determining an interactive threshold for LISS-I band 4, which was then used to mask out land areas in other bands 1, 2 and 3 (Lindell *et ai.,* 1985; Khorram and Cheshire, 1985). Masked (water) pixel values for each spectral band were extracted for 3 x 3 arrays encompassing each of the 21 and 47 sampling locations for 28 September and 20 October 1988, respectively. The LISS-I pixel values measured in DNs were converted into radiance in mW/cm^2/ìm for bands 1,2 and 3 before the regression analysis. Water is a strong absorber of band 4 (0.77-.86*ìm)* near infrared radiation and, hence, is not included in the analysis.

RESULTS AND DISCUSSIONS

The Tawa reservoir was divided into three hydrodynamic zones, inflow, transition, and main body of the reservoir (Figure 1). The inflow zones are turbid and the transition zones are relatively less turbid. The mixing of water and sediment discharge from the Tawa and Denwa rivers is observed in the main body of the reservoir, where turbidity is less than in the other two zones.

The reservoir water was alkaline in nature (pH 7.8). The conductivity reflects the chemical characteristics of the water discharged by the river into the reservoir. A significant difference in conductivity values was observed in both flanks (Tawa and Denwa) and a combined effect of both rivers water in the main body of the reservoir water. The average conductivity values are 291.9 ìs cm^{-l}, 142.3 ìs cm^{-l} and 225.4 ìs cm^{-l} in the waters of the Tawa and Denwa rivers and in the main body of the reservoir. This suggests that the Tawa River discharges more chemicals than the Denwa into'the reservoir.

Water transparency is primarily controlled by suspended load (Choubey, 1990). Figure 2 shows that the secchi depth (SD) measurements of light extinction decreases when the concentration of suspended solid increases, which indicates that SD is inversely related with suspended solids concentration.

The seechi depth (SD) measurements varied considerably for various reaches of the Tawa reservoir (Table I). On the Tawa inflow zone of the reservoir, the SD varies between 21 and 30 cm. The low water transparency is due to the heavy suspended solids loading from the river outlet. In the transition zone, water transparency gradually increases and the water becomes more homogeneous with a SD of 30-35 cm. The abrupt change in a few locations (example s1. No. 16) indicate influx of supended load from small tributaries joining the transition zone. In the Denwa inflow area, the SD values are comparatively low, in range 13-25 cm, which indicates the presence of a high

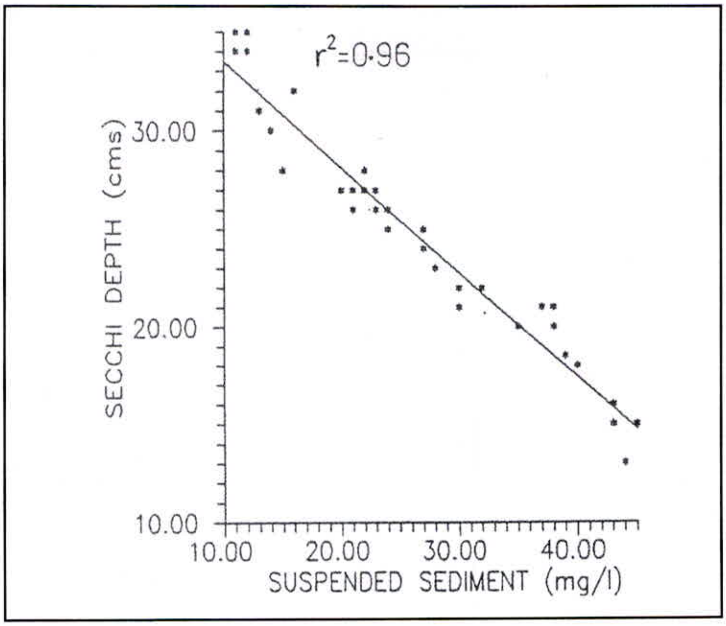

Fig 2 . Relationship between suspended solids and secchi depth

concentration of suspended solids discharged by the river. On the other hand, in the main body, due to intense mixing of river sediment laden with water, the SD is between 22-27 cm. The maximum suspended solids loading appears to be from the Denwa region.

A plot of SD against radiance values for each LISS-I band (Figure 3) indicates that as the SD values increase, there is a decrease in the radiance value. It was noticed that bands 1 and 2 exhibit hyperbolic curves and a flat response beyond 25 cm. This indicated that bands 1 and 2 (0.45 to 0.59*ìm)* approach saturation above a SD of 25 cm. However, band 3 *(0.62-O.68ìm)* shows a consistently decreasing linear trend and a high correlation (r = 0.89). The relationship between SD and radiance suggests that the water clarity depends on the concentration of suspended solids and on the physical and optical properties of suspended matter (primarily inorganic particulates).

The mineralogy characterises the nature of the suspended sediments in the reservoir water; as such they may not exactly represent the final suspended material in the reservoir after mixing (Subramanian, 1980). The reservoir's main body exhibits mineralogical characteristics between those of the Tawa and Denwa sediment discharges. The Denwa suspended sediments are coarse grained, whereas those of the Tawa are finer. Grain size-controlled mineralogy due to differential settling mechanism (Gibbs, 1967) can cause differences in the mineralogy of reservoir-suspended sediments.

The mineral composition of the suspended sediments at eight locations are shown in Figure 4. The mineral composition of the suspended sediments is an important

Table 1 : Field measured value of secchi depth and LISS-I radiance

Sample No.	Secchi depth	Band 1	Band 2	Band
1	22	4.68	3.89	2.23
2	21	4.58	3.85	2.07
3	27	4.47	3.87	2.20
4	26	4.53	3.91	2.20
5	27	4.53	3.87	2.20
6	27	4.53	3.87	2.20
7	26	4.61	4.05	2.24
8	27	4.58	3.91	2.31
9	28	4.52	3.85	2.14
10	28	4.44	3.67	2.13
11	27	4.47	3.66	2.13
12	27	4.45	3.66	2.13
13	27	4.45	3.66	2.13
13	26	4.47	3.68	2.04
14	30	4.44	3.56	1.99
15	32	4.43	3.66	2.04
16	27	4.56	3.72	2.05
17	31	4.45	2.68	1.95
Tawa transition zone				
18	34	4.43	3.55	1.95
19	31	4.45	3.49	1.97
20	34	4.42	3.53	1.93
21	35	4.42	3.51	1.81
22	34	4.43	3.56	1.81
23	35	4.36	3.56	1.81
24	30	4.48	3.72	1.93
Main body				
25	27	4.77	4.05	2.10
26	27	4.84	4.10	2.20
27	27	4.89	4.12	2.19
28	26	5.08	4.68	2.60
29	24	5.21	4.68	2.60
30	25	5.10	4.62	2.41
31	27	5.08	4.60	2.42
32	23	5.28	4.82	2.52
33	27	5.07	4.62	2.41
Denwa inflow zone				
34	22	5.32	4.95	2.93
35	18	5.34	5.12	2.93
36	22	5.07	4.78	2.86
37	19	5.35	5.09	3.00
38	26	4.90	4.11	2.52
39	20	5.20	5.00	2.90
40	21	5.30	5.01	2.92
41	21	5.23	5.01	2.94
42	20	2.26	5.01	2.94
43	15	5.43	5.24	3.30
44	25	4.93	4.70	2.93
45	13	5.38	5.20	3.31
46	16	5.38	5.20	3.31
47	15	5.33	5.20	3.

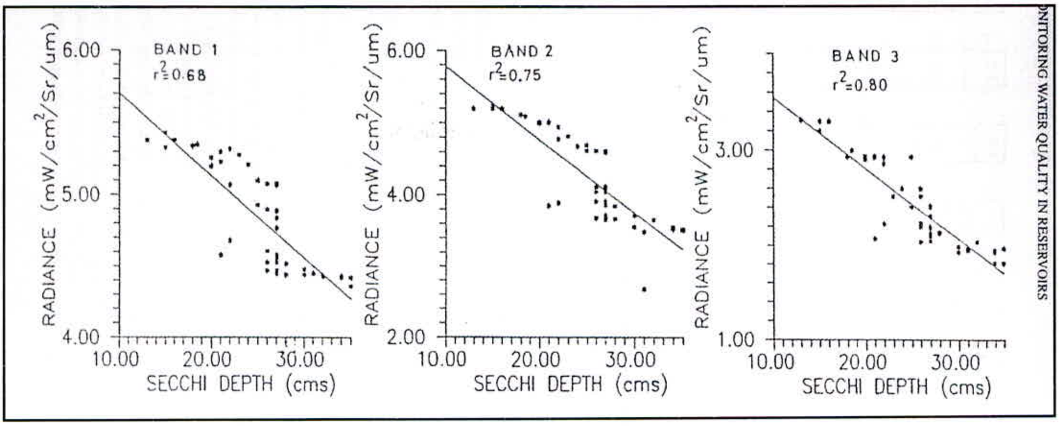

Fig 3. Relationship between secchi depth and LISS-I radiance value in band 1,2 and 3

parameter affecting the relationship between water clarity and reflected radiance (Choubey, 1990). The Tawa River contributes an equal amount of kaolinite and montmorillonite expandable clays in the inflow-transition zone and a significant amount of feldspar observed in the inflow zone. A very high percentage (70%) of kaolinite and a substantial amount of montmorillonite, illite, quartz, and feldspar are present in the Denwa inflow zone.

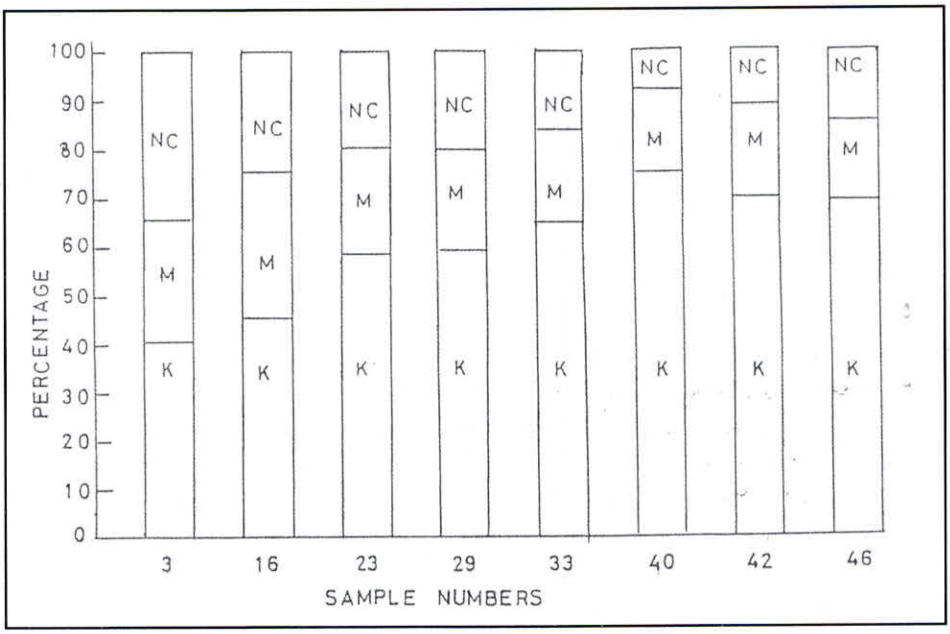

Fig. 4. Histogram of the mineral composition of suspended solids. K=Kaolinite, M=montmorillonite, NC =feldspar +quartz

The different mineralogy of the Tawa and Denwa discharge indicates that the dominance of fine clay minerals in the Denwa inflow may be the reason for the low water transparency at a more or less equal concentration in the Tawa inflow where the presence of silicates (feldspar) with clay minerals permits deep light penetration. This also suggests that water clarity depth varies with the presence of clay and non clay minerals in water.

In the Denwa region, the suspended solids concentration is comparatively higher than those of Tawa. However, the secchi depth values do not show appreciable change with change in the suspended solids concentration. Hence, it can be stated that water transparency is expected to be affected mainly by the layer of expandable kaolinite and montmorillonite clay. In this case, there is a drastic change in the conductivity of water in Tawa (291.9 ì*m* cm^{-1}) and Denwa (142.3 ì*m* cm^{-1}). Therefore, its influence on the relationship between suspended matter and water transparency cannot be ignored and needs to be studied. The conductivity is inversely related to dissolved organic material and the optimum wavelengh band 3 for monitoring water clarity is not influenced by dissolved organic matters (Topliss, 1990).

To develop the estimator equation, LISS-I multispectral digital data and field measurements of 20 October 1988 were used. A least-squares regression procedure was used to produce the estimator equation for secchi transparency in terms of LISS-I radiance values. The dependable variable was SD and LISS-I bands 1, 2, and 3 radiance values were independent variables. Forty-seven data points of 20 October 1988 from the Tawa reservoir surface water were used to obtain the estimator equation for SD.

In order to increase the analytical range, a multiple band approach was adopted. All the possible combinations of the independent variables were tested so as to find the most efficient equation. An optimum estimator equation (Table III(a) is obtained on the basis of the highest correlation coefficient approaching unity; the minimum standard error aproaching zero and the F value four times greater than a critical value for F (Fir) (Whitlock *et al.,* 1982). The relationship between observed and estimated values for the 20 October 1988 data set are shown in Figure 5(a),

Table 3 : Multiple regression equation used to estimate value of secchi depth from 20 October 1988, LISS-I mean radiance values. For verification 28 September 1988 Liss-I mean radiance values were used

$Y_{SD} = a - bx_1 + cx_2$

Where Y_{SD} = Secchi depth expressed in centimeters

x_1 = (band 1+ band 2+band 3).

x_2 = (band 1+ band 3).

a = 72.97, b = 0.85, c = -1.99.

Table 3b : Statistical summary for the multiple regression equation based on 20 October 1988, LISS-I mean radiance values

	Secchi depth
Coefficient of Determination	0.887
Coefficient of Correlation	0.942
F value	161.62
R.M.S.E.	1.83
F/Fir	
(0.01 level)	31.13
Residual range	-7.99 to 4.54

and the statistical parameter in Table III(b). The estimator equation has given good agreement with field data of the SD, where suspended sediments are dominant.

The distribution of points around the 1: 1 line is suggesting little or no bias in the data. Some of the scatter reflects an error in the field measurements of SD, which is around 10% (Davies-Colley and Vant, 1988). The time lag between IRSIA overpass and

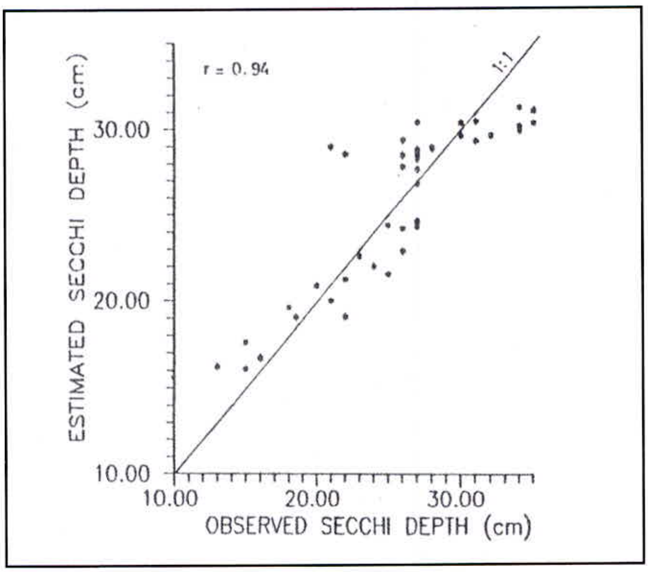

Fig. 5 (a) : Relationship between field-measured and estimated values of secchi depth from multiple regression equation using 20 October 1988 LISS-I radiance data.

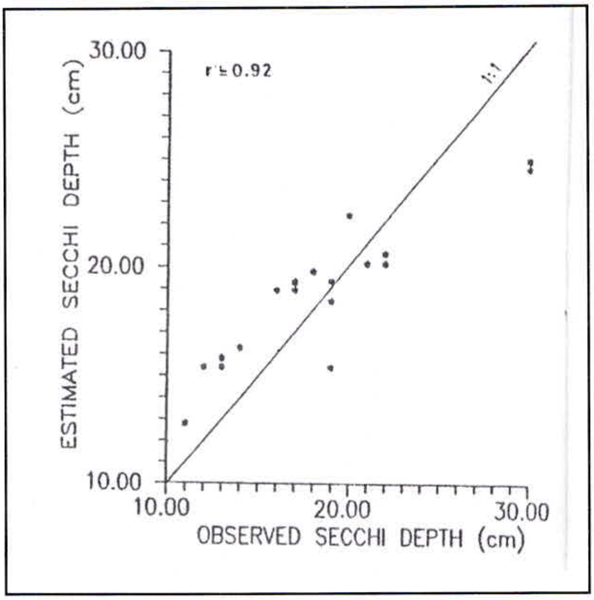

Fig. 5 (b) : Relationship between field-measured and estimated value of secchi depth from developed multiple regression equation using 28 September 1988 LISS-I radiance data for equation verification.

SD measurements (6 to 7 hours) may introduce an error. The SD values are underestimated at high SD, which may be due to the presence of 10% organic matter (pigment) in suspension. The probable reason for overestimation at low SD may be the increasing inhomogenity in the suspended solid distribution in the sampling locations.

The verification of the estimator equation was tested by applying it to the 21 data sets of 28 September 1988 bands 1, 2 and 3 radiance values for the Tawa reservoir. The relationship between field-measured values and values estimated by the equation are shown in Figure 5(b), which shows the validity of the estimater equation as data points are scattered around the 1: 1 line. The effect of unequal illumination caused by changing sun elevation angles from one IRS-IA pass to the next appears to be at its minimum (2: 45 deg). The coefficient of correlation and standard error was r=0.92 and 1.36 cm respectively. This indicates that The estimator equation appears to be satisfactory for prediction water clarity in the Tawa reservoir.

CONCLUSIONS

The result from this study may help to determine the water quality of the Tawa reservoir. On the basis of the results obtained, it can be concluded that:

(1) a functional inverse relationship exists between SD and LISS- I radiance values in the wavelength range 0.45-0.68ìm. The Tawa reservoir water calibration of SD and

band 3 of LISS-I shows a good correlation (r = 0.89, n = 47) in the range of 13-35 cm;

(2) The coefficient of correlation between observed and estimated SD data for the 28 September 1988 data set was r= 0.92, indicating that the equation could accurately predict the water quality for this reservoir on new occasions from IRS-IA-LISS-I spectral data;

(3) IRS-IA-LISS-I multispectral data are well suited for water quality mapping, since the LISS-I spectral bands 1, 2 and 3 (0.45-0.68ìm) are located in the visible region, having penetration capability in water;

(4) A generalised estimator equation can be developed considering varying conditions of sun illumination angle, algal pigment and hydrodynamic conditions during different seasons of the year;

(5) The water quality is primarily controlled by the concentration, and physical and optical properties of the suspended sediments.

(6) Further study on the effect of optical properties of water constituents (suspended matters) on the reflectance may be useful to enhance the utility of remotely sensed data for water quality monitoring.

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