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REMOTE SENSING APPLICATIONS FOR SEDIMENTATION STUDIES IN RESERVOIRS

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ABSTRACT

The suspended material discharged by river into reservoir, transport pollutants and are the natural material that fill channel and reservoir. The input of suspended material to reservoir is variable in concentration and composition from river to river, as well as changing with time in any particular river. The variation in average concentration is related to seasonal changes in precipitation and runoff within the drainage basin of river. The composition of the suspended material discharge by rivers into reservoirs varies from river to river, depending on the composition of the rock and soils in the rivers drainage basin, the weather climate to which these rocks and soils have been exposed and the energy of river to transport various size of material. Remote Sensing of reflected solar radiation can provide timely and repeated information covering suspended sediment flow pattern in reservoirs.

The purpose of this report is to describe available remote sensing techniques involving sensors on board the satellite such as MSS, TM, etc. to estimate the sediment loads of reservoir. The report attempt to discuss the methods used by the investigators all over the world viz. stepwise multiple regression analysis, chromaticity analysis, principal component analysis. The report also brings out the ground truth survey strategy and sample collection, storage, in the field and water, sediment analysis in the laboratory and field measurement. The report also stresses the need for mathematical modelling

to predict the reservoir sedimentation.

Few case studies from India and abroad conducted by various investigators using various remote sensing techniques for estimating suspended sediment concentration in inland and estuarine system.

Scope of the report:-

The prime objective of the report is to bring about the development of remote sensing application in reservoir sedimentation. The report highlights the various remote sensing techniques available, ground truth measurement method and sensors on board the satellite for the monitoring water quality parameters primarily suspended sediment concentration.

1.0 INTRODUCTION

Sediment is considered the major component in stream, reservoir, estúaries and lakes. Although sedimentation is a natural process, the rate can be accelerated or decelerated by man's activity in the acquatic environment. The dissolved and sediment loads of a river are both derived from rock weathering. The rate of supply indicate the stability of the basin. Most recent estimates indicate that the river carry annually 13.5 billion tonnes of sediment (Millimen & mead 1983) and 3.2 billion tonnes of dissolved solid (Meybeck 1979). Indian river carry sediment load of about 1.4 million tonnes/yr. representing 10% of the global sediment flux. Subramanian (1978) estimated that at the present rate of erosion, with no compensating uplifting mechanism, river basin in India would achieve their base level of erosion in 5 million years.

The suspended material discharged by river into reservoir, transport many pollutants and are the natural material that fill channel and reservoir. The input of suspended material to reservoir is variable in concentration and composition from river to river, as well as changing with time in any particular river. The variation in average concentration is related to seasonal changes in precipitation and runoff within the drainage basin of rivers. The region of extreme seasonal variation in precipitation and runoff also have the widest variation in suspended material concentration and region having reasonably steady climate have the least variation in suspended material concentration. The effect of man on the increase of suspended material concentration and discharge of river has been striking. The cutting of forest planing for formland and the multiplicity of construction project associated with man's industrial and residential expansion have markedly increased the concentration and discharge of suspended material.

The composition of the suspended material discharged by rivers into reservoirs varies from river to river, depending on the composition of the rocks and soils in the river's drainage basin, the weathering climate to which these rocks and soils have been exposed and the energy of river to transport various sizes of material. The various mineral that make up the suspended material all have different size distribution. Superimposed upon the inorganic fraction of the suspended material transported by river in the natural biologically produced material in the river generally amounting to only few milligram per litre of organic material. In addition to contributing natural material to rivers and reservoirs, man is responsible for permitting such suspended matter as solid sewage and industrial wastes in the form of metal, plastics, and wood etc. to enter the water.

The large sized sediment entering the reservoir are deposited near the mouth of the entering stream. These particles are trapped within the reservoir with near 100% efficiency. The finer sized sediments, clays, silts, and organic debris, remain in suspension and become mixed with the reservoir water, as the inflowing water are mixed with the existing impounded waters.

Present methods used to measure the concentration of these suspended sediments involve the collecting and processing of discrete samples which require considerable labour at a given time and place in the field, as well as time and labour for tedious analytical procedure in the laboratory.

The successful management of large reservoirs will be enhanced if information concerning the suspended sediment budget of the reservoirs in current and available at all times. Decision regarding reservoir management would be aided greatly if a relatively cheap, efficient and accurate means were available for determining the instantaneous suspended sediment load in large bodies of water on a continuing basis.

Remote sensing of reflected solar radiation can provide timely and repeated information concerning suspended sediment flow patterns in reservoirs. Studies have shown that quantitative relationship exist between suspended sediment concentration and reflected solar radiation (Weishlatt et al 1973; Yarger et al. 1974). In situ (Ritchie et al. 1974, 1976) have shown a high correlation (r= 0.90) between the concentration of suspended sediments in surface water of reservoirs and the amount of reflected solar radiation. Besides monitoring of the concentration of suspended sediments, the surface area of the impoundment may easily be determined by remote sensing. By utilizing some usually available morphometric data, the surface area may be related to lake volume when lake volume is highly variable, e.g., flood control reservoirs.

Knowing that estimates of the suspended sediment concentration in surface water can be made within known 1 mit of error, the relevance of the concentration of suspended sediments in the surface water of a reservoir to the total suspended load of sediment load of sediment in reservoir must be established.

2.0 REVIEW

Many investigators have used remote sensing techniques for water quality mapping landsat and skylab MSS imagery and conventional aerial photographs have been used for detecting water pollution plumes and mapping sediment distribution pattern (Strandberg 1966; Klooster and Scherz 1973; Scarpace et al. 1974; Sherz etal. 1975; Klemas etal. 1976). A number of studies have shown correlation between remotely sensed MSS data and water quality parameters such as suspended solid, secchi disk extinction depth, Jackson turbidity unit for inland waters and estuarine system (Yarger et al. 1974; Bressette 1974; Kritikos et al. 1974; Klemas et al. 1974; Brooks 1975; Lillesand eta al. 1975; Roger et al. 1975; Johnson 1975; Johnson et. al 1977; Johnson & Haris 1980).

Landsat and aircraft MSS digital data have been used for water quality mapping of inland and estuaries system by many investigators Scherz et al. (1975) and utilized multispectral data to study the distributions of pllutant and algae in ocean and inland water. Landsat multispectral scanner data have been used to map concentration of suspended sediment Klemas(1973); Williamson and Grabeau (1973) Johnson et. al. (1975), Rogers et. al. (1975) Ritchie (1976), Johnson (1978) applied regression techniques to calibrate landsat data and map distributions of chlarophyll and other water quality parameters. The same techniques have been used to map turbidity and total suspended solids (Yarger et. al 1973; Kritikos et. al 1974) Brooks, 1975; Khorram 1981, Curren et al. 1987;

Rimmer 1987). Landsat data have also been used to map salinity, turbidity, chlorophyll, suspended sediment in estuarine system (khorram 1982, 1985). The chromaticity technique outlined by Alfoldi & Munday (1978) and application involving suspended sediment reported by Amos and Alfoldi (1979), Munday, Alfoldi and Amos (1979) and Duffus and Press (1981), Carpenter (1983), Bukata et.al (1983), Lindell (1986).

Several investigators have studied the applicability of landsat data in determining & monitoring water quality in reservoir, lakes and estaurine system (Mc Keon and Rogers 1976; Rogers et. al 1975; Johnson and Harriss 1980)

Nimbus 7 - Coastal Zone Color Scanner (CZCS) was designed to detect chlorophyll suspended solid and gelbestroffe in combinations and concentrations typical of near shore and coastal waters on continental shelf. Hovis and Leung (1977) showed that a good correlation exists between suspended sediment concentration and measured upwelling radiance recorded by the CZCS. Their results, derived using simple band ratio, discriminated SSC to approximately 100 mgL^{-1} Thus they concluded that the CZCS could be used for quantitative interpretation of water quality. It therefore appeared likely that the the sensor would discriminate inorganic suspended particulate matters in an estuarine system, large reservoirs, where levels of suspended sediment concentration is high. More acurate models for chlorophyll and turbidity concentration have been developed using ocean color scanner data (Khorram 1981) because of narrower wavelength range.

In the last few years enormous amount of development in usage of remote sensing techniques in the fields of natural resources such as, Geology, Agriculture, Forestry, Hydrology, Land use etc.have taken place in the country. Although very limited work has been done in the water quality mapping.. (Suspended sediment turbidity, salinity, chlorophyll) in river, reservoirs, lakes, estuarine systems. Deekshatulu (1981), ST Chori et. al (1983), used aircraft and landsat MSS data for Hussainsagar lake and Godavari river water quality mapping. Muralikrishna (1983) and S.R. Nayak (1983) analysed landsat data around Gulf of cambay for sediment mapping. Study on spectral signature of water bodies with different turbidy has been done by Deekshatulu and under controlled condition by Muley et. al (1986). Multidate MSS data used for Wuler, Dal, Chilka lake and Rihand reservoir for water quality mapping by Muley (1986).

For years water quality has been based on point sampling and interpolation techniques. The large size of reservoir, estuaries and the spatial variability of water quality parameters has limited the effectiveness of these techniques. From the view point of measuring water quality using landsat, considerable work has not been done in India. Therefore there is a need to investigate the usefulness of landsat data for mapping of water quality parameter primarily suspended sediment, turbidity and determining environmental impact on land use practises in the basin.

3.0 SENSOR SYSTEM ON BOARD THE LANDSAT SATELLITE:

The sensors included the multispectral scanner (MSS), return beem vidicon camera (RBV) and the thematic mapper (TM). However, the focus here will be only on the MSS and the TM systems.

The Landsat multispectral scanner system collected useful earth resources data of the world. MSS data have been used extensively by scientists in a wide variety of applications. Six parallel detectors sensitive to four spectral band in the electromagnetic spectrum. These band designated as 4 (0.5 to 0.6 μm), 5 (0.6 to 0.7μm), 6 (0.7 to 0.8μm), 7 (0.8 to 1.1μm). The instantaneous field of view of each detector was square and ground resolution approximately 79x79m (67143 ft^2). The data quantized to 6 bits with a range of value from 0 to 63. these data were than rescaled to 7 bits (0 to 127) for three of the four bands in subsequent ground processing. The IFOV of 79 x 79m became about 56 m on ground between each sample. The 56 x 79 m area is called a landsat MSS picture element. The MSS scanned each line from west to east. A typical scene contained approximately 2340 scan lines with about 3240 pixel per line or about 7581600 pixel per channel. All four bands represented a data set of more than 30 million values.

The thematic mapper (TM) sensor system is a scanning optical mechanical sensor system that records reflected & emitted energy in the visible, reflective infrared, middle infrared & thermal infrared region of the electromagnetic spectrum. It collects multi-spectral imagery that has higher spatial, spectral and radiometric resolution than the landsat MSS. Landsat TM have a ground projected instantaneous field of view (IFOV) of 30x30m. Effective classification accuracy should be obtained for fields 240x240 m in size if a 30x30 m ground IFOV is used. The thermal infrared band 6 has a spatial resolution of 120x120 m. The equatorial crossing time is 11.00 A.M. TM have improved level of quantization from 6 bits to 8 bits per band. For the study of suspended sediment TM can be more effective than MSS in providing information of water quality parameters.

3.1 The SPOT Sensor System

The spot sensor system developed by French has a spatial resolution of 10 x 10 m and 20 x 20 m. The payload consists of two identical high resolution visible (HRV) sensor systems and a package comprising two magnetic tape data recorder and a telemetry transmitter. The HRV sensors can operate in two modes in the visible and reflective infrared, portion of spectrum a panchromatic mode, corresponding to observation over a braod spectral band (B&W photograph) and a multi-spectral (Color) mode, corresponding to observation in three narrower spectral bands. The ground spatial resolution is 10x10m in first case and 20x20 m in the second at nadir. The SPOT sensors may acquire stereoscopic pairs of image of a given geographic area. The stereoscopic image obtained using base height ratio is of use in photogrammetric applications such as cartographic work at 1:100,000 scale and map updating at 1: 50,000. (Details of the Landsat sensors, NOAA series, Nimbus, Hemm, Aircraft MSS listed in the Table 1). I.R.S. Orbital Remote Sensing satellite - the principal components of the IRS system are (a) three axis stablized pola sun synchronous satellite with suitable MSS(b) Ground based data reception, recording and processing systems for the multispectral data (c) Ground systems for the inorbit satellite control including the tracking network with the associated supporting softwares (d) hardware/software elements for the generation of a variety of user oriented data products, data analysis & archival. Four spectral bands 0.45-0.52 micron, 0.52-0.59 micron, 0.62-0.68 micron and 0.77-0.86 micron. The first band (0.45-0.52 micron) sensitive to sedimentation, local time for the satellite passage over India has been fixed around 10 AM, and repetitive coverage of the same area with a period of 22 days.

TABLE 1 Remote Sensor Systems Functioning from January 1, 1980, to December 31, 1984, and Some of the Capabilities for Earth Resource Mapping*

Sensor	System resolutions								
	Spectral	Spatial (ground)	Temporal	Radiometric	Veg.	Soil-rock	Water	Atmos.	Urban
1 Landsat 3									
RBV—return beam vidicon									
Band	0.505-0.75μm	30 × 30m	18 days	6	A	G	L-N	Q	U-W
MSS—multispectral scanner									
Band 4	0.5-0.6	79 × 79	18 days	6	A	G	L,N	Q	U,V
Band 5	0.6-0.7	79 × 79	18 days	6	A,C	G	L	Q	U,V
Band 6	0.7-0.8	79 × 79	18 days	6	C	G	L-N	Q	U,V
Band 7	0.8-1.1	79 × 79	18 days	6	C	G	L-N	Q	U,V
Band 8	10.4-12.6	240 × 240	18 days	6	D	H	O	T	Y
2 Landsat 4, 5									
MSS	as above	as above	16 days	8	As above, except no band 8.				
TM—thematic mapper									
Band 1	0.45-0.52μm	30 × 30m	16 days	8	A,B	G	L-N	Q	U-W
Band 2	0.52-0.60	30 × 30	16 days	8	A	G	L,N	Q	U-W
Band 3	0.63-0.69	30 × 30	16 days	8	A,C	G	L	Q	U-W
Band 4	0.76-0.90	30 × 30	16 days	8	C	G	L-N	Q	U-W
Band 5	1.55-1.75	30 × 30	16 days	8	E	G	L	L	—
Band 6	10.40-12.5	120 × 120	16 days	8	D	H	O	T	U
Band 7	2.08-2.35	30 × 30	16 days	8	E	I	L	Q	U
3 NOAA Series									
AVHRR/2—advanced very high resolution radiometer									
Band 1	0.58-0.68	1.1 × 1.1k	14.5/day	8	A	G	O	Q	—
Band 2	0.725-1.10	1.1 × 1.1k	14.5/day	8	C	G	O	Q	—
Band 3	3.55-3.93	1.1 × 1.1k	14.5/day	8	—	—	O	R	—
Band 4	10.5-11.3	1.1 × 1.1k	14.5/day	8	D	H	O	Q,R	—
Band 5	11.5-12.5	1.1 × 1.1k	14.5/day	8	D	H	O		
4 SMS GOES Series (East and West)									
VISSR—visible and infrared spin scan radiometer									
Visible	0.55-0.720	0.78 × 0.78k	0.5 h	6	A	G	L	Q	—
Infrared	10.5-12.6	7 × 7k	0.5 h	8	—	—	O	Q	—
VAS—Improved version of VISSR with 7 channels and 12 selectable filters. Can be operated in VISSR, multispectral imaging (MSI), or sounding mode.									
5 NIMBUS Series (Research and Development)									
CZCS—coastal zone color scanner									
Band 1	0.433-0.45	0.825 × 0.825k	6 days	8	A	G	L	Q	U
Band 2	0.510-0.53	0.825 × 0.825k	6 days	8	A	G	L	Q	U
Band 3	0.540-0.56	0.825 × 0.825k	6 days	8	P	G	P	Q	U
Band 4	0.660-0.68	0.825 × 0.825k	6 days	8	A	G	L	Q	U
Band 5	0.700-0.80	0.825 × 0.825k	6 days	8	C	G	L,M	Q	U
Band 6	10.5-12.5	0.825 × 0.825k	6 days	8	D	H	O	—	Y
6 HCMM—heat capacity mapping mission									
Band 1	0.5-1.10	500 × 500 m	Day	8	A,B	G	L,M	Q	—
Band 2	10.5-12.5	600 × 600	Day/night	8	D,E	H,J	O	T	—
7 SIR-A—Shuttle imaging radar (HH polarization; 50° incidence angle)									
L-band	23.5 cm	40 × 40 m	8 h	8	F	G,K	L,M	—	U,V
8 Aerial photography (color infrared)									
1: 10000	0.5-0.9	< 0.3 m	Variable	Analog	A-C	G,K	L-N	Q	U-X,Z
1: 60000	0.5-0.9	3.0 m	Variable	Analog	A-C	G,K	L-N	Q	U-W,Z
1:130000	0.5-0.9	9.0 m	Variable	Analog	A-C	G,K	L-N	Q	U-W,Z
9 Aircraft multispectral scanner imagery (Daedalus DS-1260)									
Band 1	0.38-0.42	Variable	Variable	8	A	G	L,N	Q	U-X
Band 2	0.42-0.45	Variable	Variable	8	A	G	L	Q	U-X
Band 3	0.45-0.50	Variable	Variable	8	A,B	G	L	Q	U-X
Band 4	0.50-0.55	Variable	Variable	8	A	G	L	Q	U-X
Band 5	0.55-0.60	Variable	Variable	8	A	G	L	Q	U-X
Band 6	0.60-0.65	Variable	Variable	8	A	G	L	Q	U-X
Band 7	0.65-0.69	Variable	Variable	8	A	G	L	Q	U-X
Band 8	0.70-0.79	Variable	Variable	8	C	G	L,M	Q	U-X
Band 9	0.80-0.89	Variable	Variable	8	C	G	L,M	Q	U-X
Band 10	0.92-1.1	Variable	Variable	8	C	G	L,M	Q	U-X
Band 11	8.0-13.5	Variable	Variable	8	D,E	H	O	T	Y

TABLE 1 Cont.

Sensor	Spectral	Spatial (ground)	Temporal	Radiometric	Veg.	Soil-rock	Water	Atmos.	Urban
	System resolutions								
10 TIMS thermal infrared multispectral scanner									
Band 1	8.2–8.6	Variable	Variable	8	—	G–I	—	—	—
Band 2	8.6–9.0	Variable	Variable	8	—	G–I	—	—	—
Band 3	9.0–9.4	Variable	Variable	8	—	G–I	—	—	—
Band 4	9.4–10.2	Variable	Variable	8	—	G–I	—	—	—
Band 5	10.2–11.2	Variable	Variable	8	—	G–I	—	—	—
Band 6	11.2–12.2	Variable	Variable	8	—	G–I	—	—	—

[a] Earth resource mapping codes:

Vegetation

A. Chlorophyll concentrations
B. Carotenoid concentrations
C. Biomass
D. Surface temperature
E. Moisture content
F. Surface roughness

Soils and rocks

G. Rock typing and lineament mapping
H. Surface temperature (may include thermal inertia mapping)
I. Hydrothermal alteration
J. Moisture content
K. Surface roughness

Water

L. Areal extent
M. Land/water boundary delineation
N. Water penetration (may include turbidity)
O. Surface temperature
P. Gelbstoff (yellow stuff) concentration

Atmosphere

Q. Daytime cloud cover mapping
R. Nighttime cloud cover mapping
S. Cloud/snow differentiation
T. Cloud top temperature

Urban structure

U. Anderson level I
V. Anderson level II
W. Anderson level III
X. Anderson level IV
Y. Surface temperature
Z. Surface roughness

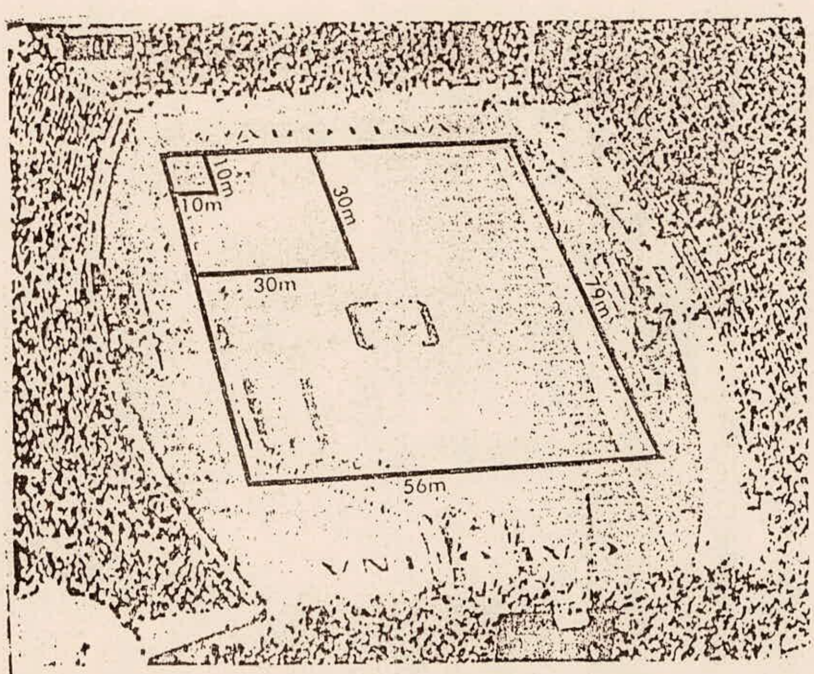

Figure 2 Diagram illustrating the spatial resolution of the Landsat MSS (56 × 79 m), the Landsat thematic mapper (30 × 30 m), and the SPOT panchromatic band (10 × 10 m).

4.0 FIELD SURVEY

4.1 Ground Truth Collection:

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

4.2 Time of Sampling:

The dynamic nature of the acquatic environment necessitates simultaneous water sample collection with satellite overpass to obtain current data required for correlating water quality parameters with remotely sensed data. Depending upon the water spread area of the reservoir a fleet of motor boat required to ensure sampling simultaneously with satellite overpass. Period of sampling should be within ± 30 minutes with satellite overpass.

4.3 Depth of Sampling:

Water samples to be representative, need to be integrated over the depth of penetration of light. This requires integrated depth samples or point depth samples later-mixed in representative proportion for assessing the water quality (Chari 1983). Depth sampler is being used for integrated or point depth sampling.

4.4 Spectral Noise Components:

The specular reflection and bottom reflectance should be considered during sampling. Specular reflection can be reduced by suitable satellite overpass time during low sun-angle the bottom noise could be avoided by selecting sampling points with sufficient depth.

4.5 Sampling Site Identification:

Sampling point with reference to landmark, cultural features, island, range line etc., could be located precisely from large scale topographical maps. The location of the sites can than be transferred from topographical map into image, wind speed and direction can be measured at a height of 2m using band held anemometer when condition on the reservoir favourable velocity measurements can be made using electromagnetic current meter. Depth can be measured using echosounder.

4.6 Water & Sediment Collection, Preservation, Storage and Analysis:

Since water quality mapping based on satellite data involves multiple regression analysis between water quality parameters and reflected and emitted radiation in different wavebands the sample size should be large. A factor of redundancy should also be built in so that unsuitable sampling point can be edited out and still leave a big enough sample size to enable regression analysis.

The water samples collected simultaneous with satellite overpass should be analysed for turbidity, pH, Temperature, specific conductivity, dissolved oxygen in the field by using turbidometer, water quality testing kit. Water samples can be collected in jerry cans for general analysis, and BOD bottles for BOD, COD, DO and Chlorophyll determination. Samples collected for chlorophyll measurement should be covered by black paper to retard algal growth. The samples should be analysed within allowable limit. For instance color should be determined within 24 hours, chloride can be measured within 7 days.

Details of sample, numbers, location, time, should be carefully recorded to enable subsequent information retrieval sample containers i.e. Jerry can, BOD bottles, should be securely lebelled for identification in the laboratory collected water samples should be kept in cool place or in field ice boxes could be used to store water samples at low temperatures.

The samples should be analysed as soon as possible after collection Preservative could be added when necessary. Samples should be analysed in laboratories for total dissoslved solids, total suspended solids BOD, COD, alkalinity, hardness, calcium, magnesium, chlorides, sulphates, phosphates, sodium, potassium, nitrites, nitrates, chlorophyll laboratory analysis help to identify spectrally relevant water samples, parameters through regression analysis.

5.0 COMPUTER COMPATIBLE TAPE DATA CORRECTION

The remotely sensed data that needs to be considered for the study of water quality parameters primarily suspended sediment is to account for sixth line banding. Correction for sixth line banding involves an analysis of the whole image segment by calculating and manipulating the means and standard deviation for each of the four detectors for each of the six lines. The basis of this method of correction is that, for a large segment the average response level recorded should be the same.

5.1 Rectification of the Imagery

The method of rectification involves spatial resection to ground control point using cubic polynomial (Lodwick 1978). Usually control points comprise naturally occuring features. These points need to be locations on the earth's surface that have been precisely surveyed. The important requirement are that the location accuracy be commensurate with the scale of the mapping to be done from the image and that the control points be easily and uniquely identifiable. The coordinates of the control points can be identified from 1:50000 or 1:250000 topographical maps. The third order polynomials may be used in the resection are solved by least square procedure both ground and image coordinates being may consider subject to error (Lodwick 1985). Appropriate variances are assigned to the image coordinates according to the estimated accuracy of measurement, and to the ground coordinates according to the assigned map accuracies and estimated pointing errors. The water quality sample points were than can be located on the landsat data through transformation of latitude and longitude. The mean count values on all MSS bands can be extracted for the pixel block encompassing each sampling site.

5.2 Atmospheric Correction of Landsat Data

Use of multidate satellite image data requires that sun angle and atmospheric effect be accounted for in order to infer the reflectance of targets on the earth surface. Ahern etal. (1975) described technique which does not require ground measurement of solar radiations. The method successfully applied by Richardson(1980). In this approach model of interaction of solar radiation with the atmosphere is stated as:

$$Lsat = r\ TH_{tot} + Lp$$

where Lsat is the radiance in a given spectral band ($mW/cm^2\ Sr$), r is target reflectance, defined as the ratio of upwelling radiance to downwelling irradiance (Sr^{-1}), T is atmospheric transmittance, from surface to satellite, H_{tot} is total irradiance incident on a horizontal surface at the bottom of the atmosphere ($m\ W/cm^2.Sr.$) LP is atmospheric path radiance (mW/mxr) Value of Lsat are computed from the digital counts (Tobinove 1982) by :

$$Lsat = \frac{DC}{DC\ Max} (L_{max} - L_{min}) + Lmin$$

Where DC is digital count for a pixel of interest, DC max is maximum digital count for the band of consideration(127 for bands 4, 5 and 6; 63 for band 7), Lmax is radiance yielding detector saturation, Lmin is lowest radiance. Target reflectance r is an observational quantity and differs from ρ , the reflectance of a Lambertion surface $\rho = \pi r$ where

is represent ratio of upwelling to downwelling irradiance. Atmospheric transmittance T from surface to satellite defined as :

$$T = \rho \ (- T \text{ Sec } Qn)$$

where T is the total optical depth of the atmospheric and Qn is the satellite nadir view angle. Total irradiance, H_{tot} is made up of direct and diffuse insolation i.e.,

$$H_{tot} = H_o \text{Cos} Z \ e^{(-T \text{ Sec } Z)} + H \text{ sky}$$

where H_o is the solar irradiance at the top of earth's atmosphere (m W/cm^2) Z is the Solar Zenith angle, and H_{sky} is the irradiance on a horizontal surface due to diffuse skylight.

6.0 ANALYSIS TECHNIQUES

Interpretation techniques are either visual or computer aided . The simplest techniques is to interprete multidate, multiband black and white transparencies, paper prints by using optical enlarger or photographic enlargement. The use of color additive viewer does not improve the contrast (Klemas 1980). Hybrid ratio color composites prepared using diazo techniques are useful. The density slicing technique, the range of grey level can be observed in an image represent different range of reflectance value and thus different concentration level of suspended sediment can be delineated.

6.1 Comparison of Image and Site Data

To compare the satellite data to the ground truth data a simple linear regression algorithm can be used. From this correlation coefficients which measure the linear relationship between the landsat data and ground truth data.

6.2 Multiple Regression Analysis

The water quality sample point could be located on the landsat data through transformations to latitude and longitude. The mean count value on all bands can be extracted for the pixel blocks encompossing each sample sites. These mean count value could be used as independent variable in the regressin models. The land/water interfac e can be identified and marked so that only water should be analysed. This can be done by marking function taking pixel value corresponding to land to zero. Correlation matrices can be produced for all water quality parameters and for all bands and number of band combinations and ratios. The selection of bands and band combination based on correlation matrices may be used in the statistical analysis of all possible combinations. Then the statistical models can be examined for determining the best relationship between each of the water quality parameter measurements, and the mean count value from landsat bands data and their ratios and combinations. The determination of best regression fit for each of the selected water quality parameter will be based on R^2 value, the 'F' value, the significance of these F values the residual value and simplicity of model.

Khorram 1981, 1985 developed regresion models for water quality parameter and observed coefficient of determination (R^2) was high for salinity and turbidity, relatively high for chlrophyll and medium for total suspended solid. All the parameters in the models for salinity, chlrophyll, and total suspended solid were significant at the 95% confidence level using T Test.

6.3 Chromaticity Analysis

The chromaticity analysis of satellite data is in essence a graphical display of the color component of the data (Alfoldi 1978). The irradiance reflectance (volume reflectance) spectrum beneath the surface of a water mass is in control of absorption and scattering phenomena associated, with suspended and dissolved organic and inorganic component of the water mass. The chromaticity technique as described by Munday and Alfoldi (1975, 1978, 1979); Hardy and Jefferies (1981) has been used for water quality mapping. Munday and Alfoldi's approach has been further developed for automatic mapping of suspended sediment load using microcomputerised system by Lindell and Karlsson (1986). The modified system uses absolute radiance value from the satellite and explicitly treat solar angle variation and atmospheric disturbances.

By using the chromaticity coordinate it is possible to correct for sun angle effects and atmospheric differences. These techniques eliminate disturbances affecting all bands in the same proportion. The chromaticity indices X and Y are calculated by:

$$X = \frac{R4}{R4 + R5 + R6}$$

$$Y = \frac{R5}{R4 + R5 + R6}$$

Where R4, R5 and R6 denote the radiance in landsat band 4,5,6 respectively. This transformation coefficient is similar to CIE (commission international de i Eclairage). Multi-spectral scanner band 7 is ignored because water absorb 800 to 1100 nm consequently only very high concentration of near surface contamination will produce MSS 7 radiance above back-ground levels. These two coefficients are sufficient in describing spectral (color) features of the three MSS bands of interest, because in forming X & Y one of the three MSS degrees of freedom is utilized to normalize by total radiance. Chromaticities described by X & Y can be plotted as point on a graph and interpreted as CIE chromaticity diagrams. Normalisation by total radiance removes brightness information to eliminate noise, when all bands suffer radiance changes in the same proportion to get spectral or color effect. Mathematically, analysis proved that the chromaticity transformation is the only isoluminous/equal radiance transformation which retainsall the spectral information of these three channels without color distortion (Munday & Alfoldi, 1975).

Amos (1985) observed that the chromaticity techniques can be used only if radiance is measured in three separate wavelengths within the visible part of the spectrum. The method assumes that the measures of a radiance co-vary predictably over the range of water quantities to be discriminated by the satellite. These attributes have yet to be demonstrated appropirate for the application of Nimbus 7 coastal zone color scanner in the discrimination of suspended perticulate matters. Topliss reevaluated the chromaticity method by comparing the original data set to insitu measurement of irradiance within the bay of fundy and concluded that only a slight increase in the scatter of data (1-3%) could be explained using chromaticity method over a simple spectral band ratio (4/5). Carpenter & Carpenter(1983) concluded the same from measurement made in Australian water where in the six cases reported linear model, explained upto 95% of the observed variance.

6.4 Principal Component Analysis

Principal components analysis is useful for the analysis of 4 band data set because it can usually reduce the spatial complexity of multivariate problem. Principal component analysis techniques involve an orthonormal transformation which produces a rotation of the image data set but individual points retain their relative positions through the transformation. The method involves setting up a variance covariance matrix and recalculating scores for the samples along the principal components axis or (eigenvectors) which represent new variable. These new variables identical in number to the original ones, are linearly independent and the total variance calculated for the scores is identical to the variance in the original bands. However with the landsat data because of the high correlation between the original bands, the first and second principal components (PC1 and PC2) typically account for more than 95% of the original variance mostly land and vegetation (Lodwick 1977). Thus the original spectral position of a particular data element can be defined in terms of a vector in two dimensions with negligible loss of information and this can be compared to those of other elements. Standardisation is carried out simply by adjusting the distribution of each band to a mean of zero and deviation of one. In this way, bands which have a greater dynamic range (usually band (6&7) will not contribute a disproportionate amount of variance. Lodwick (1985) concluded that landsat data and principal components analysis to depict sedimentation in water bodies is a real one. PC 1 scores of the landsat data correlate quite well with the total suspended sediment statistics.

The correlation coefficient is approximately 0.8 in all the three cases. This indicates that 0.8^2 or 64 percent of the information on total suspended sediment is contained in PC 1 of the landsat data PC 2 (band 4 & 5) shows poor correlation because of bottom effects. PC 3 correlates well with conductivity at the surface.

7.0 CASE STUDIES

7.1 Global

Many investigators have used remote sensing techniques for mapping of water quality parameters. Landsat, skylab MSS imagery and conventional aerial photographs have been used for mapping sediment distribution pattern in reservoir, estuarine system. A number of studies have shown correlation between remotely sensed MSS data and water quality parameters such as suspended sediment, turbidity, chlorophyll.

Yarger et. al (1973) have examined several landsat images of ninteen reservoirs in the Kansas State, USA. Yarger concluded that MSS bands and ratio can be used for reliable prediction of suspended load upto 900 ppm. They have established a quantitative correlation between film density and turbidity with repeated coverage and sampling.

Moore et. al (1974) suggested a procedure for using landsat image to classify lake, turbidity and color and thereby reduce the necessity for field sampling and analysis of water. They concluded if a ground based sampling programme was developed this procedure may be helpful for selecting lakes with widely differing physical and chemical qualities.

Khoram (1985) used landsat multispectral scanner data combined with surface measurements for water quality parameters such as salinity, chlorophyll, turbidity and total suspended solids, of the Neuse River estuary, North Corolina. He has collected water sample from boats of 75 sample sites simultaneous with satellite overpass, and regression model were developed between each of the salinity and suspended solid measurement from boats and the MSS digital data for sample sites. Khoram observed coefficient of determination (R^2) was high for salinity and turbidity, relatively high for chlorophyll and medium for total suspended solid.

Lodwick et.al (1985) investigated the feasibility of using principal component analysis to compare landsat data with water quality statistics for the lake Athabosca. Principal component analysis were carried out on field data set and landsat data set. They concluded that PC 1 (band 6 & 7) scores of the landsat data correlate quite well with total suspended sediment statistics. The correlation coefficient was 0.8 in all cases. PC 2 (band 4 & 5) did not correlate well with suspended sediments.

7.2 Indian

Sahai et.al (1983) used MSS data to identify sedimentation levels in Ukai reservoir. Each band was analysed separately using density slicing techniques and then superimposed on each other, and identified 10 turbidity levels.

Rao et.al (1978) carried out study for spectral signatures of water bodies having relative turbidities from 3 to 25 and corresponding spectral reflectance values. Secchi depth, bottom reflectance effect, depth of extinction measure of water of different turbidity values of five water bodies around Mandya town. They have correlated ground data with that of the Synchronous modular multispectral scanner data and concluded that the spectral reflectance increases much faster in lower turbidity value and absorption of radiation in water is of exponential nature.

Deekshatulu et.al (1981) have carried out water quality analysis of Hussainsagar lake in Hyderabad and Godavari river near Rajamundry using laboratory, field and airborne remote sensing techniques. Modular multispectral scanner and multiband photography data were used. Field experiments suggested correlation between turbidity, dissolved solids, total suspended solids, chlorophyll. Densitometric analysis indicate that polluted water can be discriminated from clean water. Scanner data was analysed digitally using M-DAS system to produce color coded map of water quality parameters.

Muley et.al (1986) Visually interpreted multidate multiband landsat images of wular, chilka lake and Rehand reservoir using enlargers. They concluded band 4 & 5 give better information about turbidity level present in water column but compilation of all band is essential to achieve optimum level of turbidity.

Muley et. al (1986) conducted a spectral signature experiment with fine and coarse loam to measure the reflectance under control condition. The clay and loam were inserted in various quantity at 0.5m depth in 4 m deep well and at each simulated condition the secchi depth was measured which varies from 3.2m (natural water) to 0.7m (turbid water). The comparison of reflectance of clean water and of various concentration of suspended sediments show reflectance of clear water is less than turbid water(Fig. 1 & 2).

They concluded the reflectance from suspended sediments shows that variation in turbidity could be distinguished using spectral data. Differences in 0.2m secchi depth transparency for suspended material viz loam can be deducted. Optimum bands for the study of turbidity are 448-532 nm, 572-565 nm, 505-607 nm, 624-697 nm and 712-799 nm. This depend on the nature, size and concentration of suspended materials.

Table : 2

KEY FOR THE DEMARCATION OF TURBIDITY LEVELS IN THE WATERBODY (VISUAL INTERPRETATION)

Band-4	Band 5	Band 6	Band 7	Level	Turbidity
DB	DB	DB	DB	I	Nil
B	B	B	B	II	Nil
GB	GB	DB	DB	III	Very low
BG/G	BG/GB	BG/DB	B/DB	IV	
G/BG	BG	DB/BG	DB	V	
G/BG/WG	G/GB	GB	B/GB	VI	
G/WG	G/BG	BG/GB	B/GB	VII	
WG	WG/G	G/GB	GB/BG	VIII	
WG/GW/W	WG	WG/G	G	IX	Very high

Colour Tone

DB	Dark Black	1
B	Black	2
GB	Grayish Black	3
BG	Blakish Gray	4
G	Gray	5
WG	Whitish Gray	6
GW	Grayish White	7
W	White (Bright white)	8

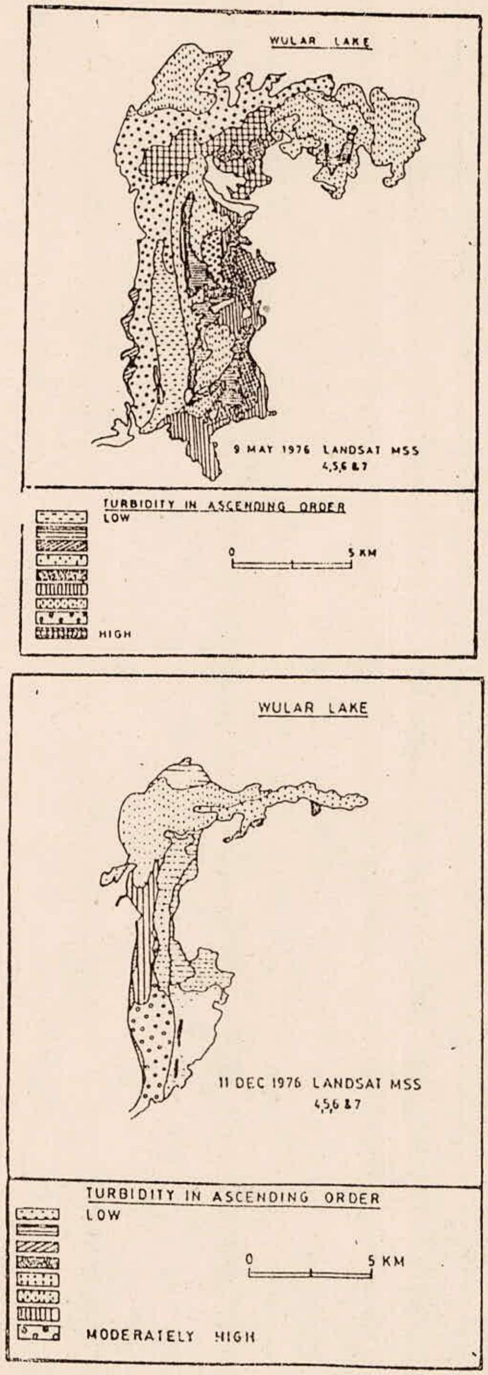

Fig.2: Turbidity levels in Wular lake as marked using multidate Landsat imagery of 1976.

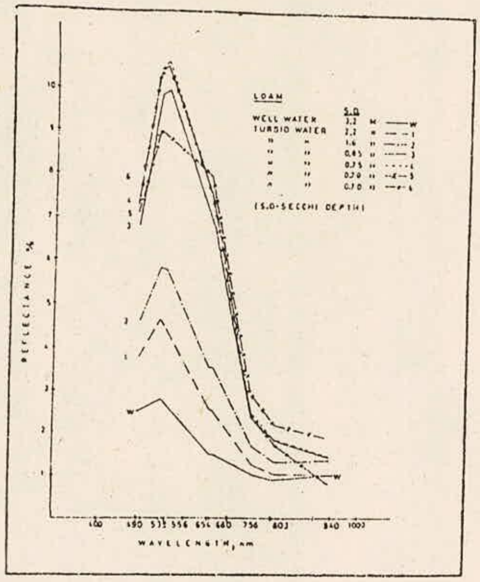

FIG. 3 THE REFLECTANCE TO SECCHI DEPTH (TURBIDITY) RELATIONSHIP OF WELL WATER WITH LOAM

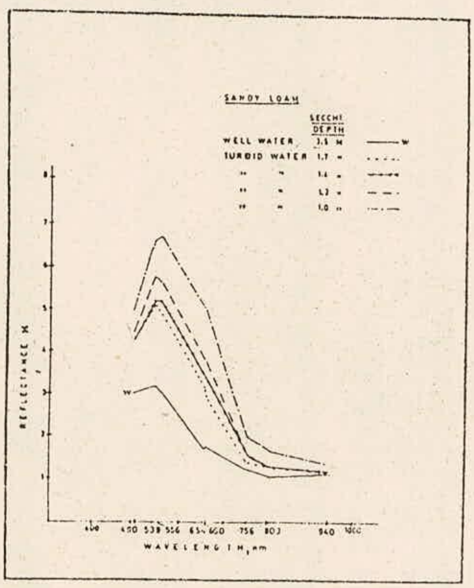

FIG. 4: THE REFLECTANCE TO SECCHI DEPTH (TURBIDITY) RELATIONSHIP OF WELL WATER WITH SANDY LOAM

8.0 CONCLUSION

Based on review of literature the following conclusion were reached:

1. The greatest advantage landsat has to offer over current method of studying sedimentation pattern are in term of convenience and economy. The cost of analysis required for such studies is small compared to the cost of outfitting a field crew to obtain the same information on each occasion. Also because of the large area covered by landsat imagery the interdependencies of one area with another can readily be seen. With field methods studies tend to be restricted to localised area, because of both times and cost constraints.

2. Landsat digital data can be successfully used to map surface water quality parameters primarily suspended sediment concentration.

3. No quantitative assessment can be made of the suspended sediment concentration by visual interpretation.

4. In order to develop generalised water quality model seasonal studies are needed in a year and under different flow condition.

5. Possibility of using Landsat data and Principal component analysis to depict sedimentation in water bodies may be explored.

6. Multiple regression model may be developed between turbidity, salinity, chlorophyll, suspended solid measurement in the field and the landsat MSS digital data. For the distribution of total suspended solid regression model may be developed with the narrower band width provided by the landsat thematic mapper data.

7. Chromaticity analysis is rapid and may be more useful for monitoring water quality programme covering a large number of water bodies spread over large area where surface data are not readily available on continuing basis.

8. Reservoir water sampling for satellite water quality survey is very difficult and stringent particularly in India where obtaining depth sampler, motar boat VHF sets, echosounder etc. are difficult. There is a need to develop ground truth infrastructure to suit Indian condition.

9. The NIMBUS 7 coastal zone color scanner was designed to detect suspended solid, chlorophyll and gelbestroffe in combination and concentration typical of near shore and coastal water on the continental shelf. Possibility of using coastal zone color scanner data to depict suspended solid in inland large water bodies may be explored.

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