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Remote Sensing-A Tool for Water Quality Monitoring

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ABSTRACT : *Man and nature both affect the aquatic environment. Man utilizes water bodies as sources of water, food, transportation and recreation. Often, the same water becomes sinks for man's wastes as well. Also significant sediment loads by natural processes are brought into these water bodies. These result in the pollution of water which, in turn, seriously effect man's life. Hence, detailed knowledge of the aquatic environment is essential to control the pollution. Conventional in-situ measurements of water quality parameters are slow, sparse and costly. Remote sensing has significant advantages over in-situ techniques in monitoring the water quality parameters because of its synoptic and repetitive nature. Qualitative and quantitative mapping of water quality parameters have been successfully carried out by many workers. In this paper, the principles of interaction of water and light, the sensors and the methodology for measuring the water quality parameters have been described. Significant results available from some case studies have also been cited.*

1. Introduction

Since water plays a vital role in a biological system, pollution of water is a most important problem. It is well known that less than 1 per cent of the total world water supply is fluid fresh water which is important to the mankind. In fact, man and nature both affect the aquatic environment. Man utilises water bodies as sources of water, food, transportation and recreation. He also often uses the same water body as a sink for man's waste. The rapid and continuous growth of industries coupled with unregulated discharge of industrial waste and municipal sewage have accelerated the degradation of water quality in rivers, lakes, tanks and esturies. Significant sediment loads by natural processes are brought into water bodies causing pollution of water which, in turn, seriously effects man's life.

Water becomes unsuitable for human consumption or for irrigation of agricultural land because of such deterioration of water quality. It also endangers the life of birds, cattle, fish and other aquatic life. Suspended sediments seriously affect the aquatic life by reducing the light penetration and by silting up the beds. Highly turbid water is unsuitable for drinking or industrial use.

Rapid and synoptic detection of pollutants is very much required to control the water pollution. For this, one has to develop new methods but at the same time conventional methods have to be improved. So far in our country insitu measurements are the basis for all water quality observations. Recently modern remote sensing techniques because of their synoptic and repetitive nature have shown potential for measurements of water quality parameters such as suspended sediments, chlorophyll concentration, salinity, temperature, etc.

2. Water Pollutants

Various pollutants that affect the water quality are listed below (Meyer and Welch, 1975).

(i) Organic waste contributed by municipal sewage and industrial waste of plant and animal origin which remove oxygen from water through decomposition.

(ii) Infections agents contributed by domestic sewage and certain kinds of industrial waste which may transmit disease.

(iii) Plant nutrients which promote growth of aquatic plant life such as algae and water weeds.

(iv) Synthetic organic chemicals such as detergents and pesticides resulting from new chemical technology are toxic to aquatic life such as algae and to human beings.

(v) Inorganic chemical and mineral substances resulting from mining, manufacturing processes, oil plant operations and agricultural practices which interfere with natural stream purification, destroy fish and aquatic life, cause excessive hardness of water supplies, produce corrosive effects and, in general, add to the cost of water treatment.

(vi) Sediments which fill streams, channels, reservoirs and harbours, cause erosion off hydroelectric power and pumping equipment, effect the fish and shellfish population by blanketing fish nets and increase the cost of water treatment,

(vii) Radioactive pollution resulting from the mining and processing of radioactive ores, from the use of refined radioactive materials.

(viii) Temperature increases which results from the use of water for cooling purposes by steam, electric plants and industries and which have harmful effects on fish and aquatic life and reduce the capacity of receiving water to assimilate wastes.

3. Remote Sensing of Water Pollutants

All water pollutants can not be sensed and measured remotely. Only those pollutants which affect the colour and intensity of reflected light of a water body can be sensed by remote sensing. For example, many dissolved chemicals have no specific spectral singnature while many suspended particulate matter have distinctive spectral signatures. Thus, any pollutant that adds to the scattering and absorption by a water body has a potential for remote detection and measurement. So it is essential to measure the color and the brightness of water to detect water pollutants. The phenomena that impart specific color and brightness to an image of water body can be classified into six broad categories :

(i) source characteristics,

(ii) atmospheric effects,

(iii) surface reflections,

(iv) volume reflectance,

(v) bottom reflections, and

(vi) sensor characteristics.

However, we are concerned with the differences in water appearance which can be recorded by a camera or multispectral scanner. Many variables (Table 1) which may affect the intensity of reflected light measured by the sensors onboard the satellite are described by More (1980).

Table 1 : Variables that can affect remote sensing of physical water-quality characteristics (Moore, 1980)

Variable	Explanation
Time of year	The earth receives 7% more energy from the Sun on January 1 than on July 1 because af an oval orbit.
Sun-elevation angle	More solar energy is specularly reflected from water surfaces at low sun-elevation angles than at high angles. Also, the path length of solar-energy through the atmosphere is longer at low sun-elevation angles and therefore more solar energy is absorbed and scattered.
Aerosol and molecular content of atmosphere	These consituents determine the amount of solar energy absorbed and scattered by the atmosphere. Some energy, received by a satellite is backscattered before reaching the water surface.
Water - vapour content of the atmosphere	Water vapour affects energy absorption at near infrared and thermal infrared wavelengths.
Specular reflection of skylight from water surface	Specularly reflected skylight is received by a satellite. The intensity and wavelength distribution of this energy depends on atmospheric scattering, which produces skylight.
Roughness of water surface	A rough surface may produce more or less specular reflection than a smooth surface. At high sun-elevation angles, the area of sun glint may be within the satellite fields of view.
Film, foam, debris, or floating plants on water surface	These features may not be resolved on a satellite image, but they contribute to the spectral characteristics of the measured signal.
Water colour	Dissolved coloured materials increase absorption of solar energy in water.
Water turbidity	The concentration, size, shapes, and refractive index of suspended particles determine turbidity and increase the amount of energy backscattered in water bodies.
Reflectance and absorptance characteristics of suspended particles	Particles may be inorganic sediments, phytoplankton, zooplankton or a combination. When present in high concentrations, particles affect the spectral distribution of backscattered energy.
Multiple reflections and scattering of solar energy in water	The spectral results of these processes are difficult to predict, but may not be important.
Depth of water and reflectance of bottom sediments	Water clarity determines the importance of bottom reflectance. Solar energy may not reach bottom in a turbid water.
Submerged or emergent vegetation	Vegetation may change bottom reflectance, obscure water surface or contribute to the spectral characteristics of the measured signal.

3.1 Physical Principles

Water parameters which affect the energy levels recorded by the sensors are colour and turbidity. An increase in water color decreases the energy flux reaching a sensor because sun's energy is more absorbed. An increase in turbidity increases the energy flux reaching a sensor because more energy is reflected or backscattered by suspended matter. However, increase in signal also occurs from shallow water due to the bottom reflectance. So, it is important to understand the principles of interaction of water and light for measuring the water quality parameters.

If the solar energy that reaches a water surface is represented by I, the interaction by Moore (1980) is

$$I_O = I_{SR} + I_A + I_B$$

I_{SR} = Solar flux that is specularly reflected at the water surface.

I_A = Flux absorbed by water

I_B = Flux backscattered to the water surface and thereby available for remote detection.

Specular reflection is equal at all wavelengths, but absorption and backscatter produce distinctive spectral signature. The percentage of solar energy that is specularly reflected from calm waters depends on sun-elevation angle. Only small amount of incoming solar energy is lost by specular reflection between 30° — 60° sun-elevation angles. However, corrections for specular reflection should be made, while measuring spectral signature of water bodies.

If specular reflection is imaged by camera or scanner it is called sunglint. Contamination of remotely measured signal by sunlight does not create a problem in water turbidity studies but corrections are required for quantitative estimation of turbidity.

Some skylight is reflected to a camera or multispectral scanner. The specular reflection of skylight generally can be ignored, corrections may be necessary under hazy conditions and for sun-elevation angles of less than 30° (Moore, 1980).

The way light is absorbed, scattered and reflected (spectral characteristics) is selective and depends on the materials in the water. In a shallow and turbid water, it is not possible to seperate signal from bottom and from the suspended sediments. The light that penetrates into the water and reaches the surface again after absorption, scattering and reflection carries information about water quality. Blue light scatters more than the red light.

3.2 Sensors

A remote sensor detects energy in different wavelengths of the electromagnetic spectrum and thus distinguishes the difference in the spectral behaviour of the objects. Sensors can be either passive or active. Passive sensors use sunlight as energy while active sensors transmit energy themselves, viz. a camera is a passive sensor when fitted with a flash, it becomes an active sensor. The instrumentation requirements for remote sensing of pollutants as described in NASA SP-285 are given in Table 2.

Photographic system uses camera with filters to record light energy of different wavelengths. Photographs can be in black-and-white, colour or colour infrared (CIR). Multiband aerial photography records subtle differences in spectral reflectance and thus provide a powerful tool to detect sources of pollution and to monitor pollutant dispersion. Pollutants may impart colour to the water and thus can be detected by colour photography. CIR photographs easily detect floating aquatic vegetation, algae and vegetation. These

Table 2. MEASUREMENT REQUIREMENTS FOR REMOTE SENSING OF POLLUTION

An optimum value and an (acceptable value) are given for each entry.

N/A—not applicable

	Spatial Resolution	Spectral Resolution	Spectral Range	Temporal Resolution	Solar Elevation	Look Angle (From Nadir)	Area Coverage
Oil	10-30m (300m)	Broad-band	Ultraviolet, Visible, Microwave	2-4 hrs. (1 day)	Only important with glitter	Only important with glitter	200x200km (20x20km)
Suspended Sediment	20m (500m)	.15 μ m (.15 μ m)	350-800nm (400-700nm)	2 hrs. (1 day)	45° (30°-60°)	0 to + 15° (− 5° to + 30°)	350x100km (10x10km)
Chem. & Toxic Wastes	10m (200m)	.015 μ m (.015 μ m)	350-700nm (400-700nm)	5 hrs. (10 days)	45° (30°-60°)	0 to + 15° (− 5° to 30°)	35x35km (10x10km)
Solid Wastes	10m (200m)	.015 μ m (.015 μ m)	350-800nm (400-700nm)	5 hrs. (10 days)	45° (30°-60°)	0 to + 15° (− 5° to + 30°)	35x35km (10x10km)
Thermal Effluents	30m (500m)	± 0.2°C (± 1°C)	10-12 μ m (10-14 μ m)	2 hrs. (10 days)	N/A	To be determined	35x35km (10x10km)
Radioactive Wastes	30m (500m)	N/A	gamma (gamma)	5 hrs. (15 days)	N/A	0° (0°)	35x35km (10x10km)
Nutrient Wastes	100m (2km)	.005 μ m (.015 μ m)	400-700nm (400-700nm)	2 days (14 days)	45° (30°-60°)	0 to + 15° (0 to + 30°)	350x350km (35x35km)
Intro. of Species	To be determined	.1 μ m (.1 μ m)	Visible (Visible)	3 mos. (yr.	N/A	N/A	350x350km (10x10km)
Red Tide	30m (2km)	.015 μ m (.015 μ m)	400-700nm (400-700nm)	5 hrs. (2 days)	45° (30°-60°)	0 to 15° (− 5° to + 30°)	350x350km (20x100km)
Human & Cultural Effects	10m (100m)	Variable	Ultraviolet, Visible, Microwave	1 yr. (5 yrs.)	N/A	N/A	350x350km (35x35km)

(Source : NASA SP-285, 1971)

photographs are not much affected by atmospheric haze.

Photographic system provides stereoscopic coverage. The advantages of stereo coverage are (Meyer and Welch, 1975).

(i) The three-dimensional view of shoreline areas improves reliability of interpretation.

(ii) A second view taken from different point provides verification of a condition observed, when sun glare from water surfaces may obscure a portion of a scene and where water currents and outfall dispersion pattern may be difficult to trace on a single photo.

Regional surveys for reconnaissance mapping are commonly carried out at 1:40,000 to 1:60,000 scale. Large scales of 1:5000 to 1:10,000 are used for detailed mapping. The combination of colour and CIR photography would be most suitable for water quality studies.

The scanner system scans series of swaths perpendicular to the flight path to get two dimensional data. The multispectral scanner (MSS) on Landsat satellite is most commonly used sensor. It has four spectral bands in visible and near infrared. Various airborne scanners are also available. Some of the scanners operate in the thermal region also. The thermal scanner records relative temperature differences. It must be used in conjunction with a temperature reference source and with actual surface temperature records obtained during scanner overpass.

Space Applications Centre (SAC) has developed a multispectral scanner which operates in visible, near infrared and thermal region.

Radiometers, spectrometers and scatterometers have been used for water quality studies. The insitu instruments using Secchi disc, Nephelometer (for turbidity measurements), ground truth radiometers (for measurements of spectral signatures of water bodies), Infrared thermometers (for temperatures of water) are used for water quality studies. Various pollution parameters monitored are chlorophyll content, oil slick identification water temperature and dye dispersion.

Various spectral ranges (sensors) which are useful for detecting, identifying, classifying and measuring areal extent and estimating concentration of water quality parameters are listed below (Meyer and Welch, 1975).

Water quality parameter	Useful spectral range
Suspended sediment	V, IR
Chlorophyll, phytoplankton	CIR, IR
Vegetation	CIR, IR, V
Lake/reservoir extent	IR
Surface temperature	TR, MW
Salinity	CIR, TR, MW
Oil spills	UV (video), TR, MW
Waste effluents	CIR, TR
Radioactive waste	GRS

V = Visible, IR = Infrared, CIR = Colour infrared, C = Colour, TR = Thermal Infrared, MW = Microwave, UV = Ultraviolet, GRS = Gamma ray spectroscopy.

3.3 Methodology

3.3.1 Visual Interpretation

Based on the following physical facts, a mapping legend has to be developed for visual interpretation of remotely sensed data (Moore, 1980).

(i) A turbid water is more reflective than clear water at all visible and near infrared wavelengths.

(ii) Spectral signatures from turbid water represent only near surface conditions.

(iii) The measured signal at any wavelength interval is dependent on particle size as well as concentration.

The legend, prepared for qualitative mapping of turbidity levels in the Matatila reservoir using IRS images is given in Table 3 (Patel et al 1988). The gray scale provided at the bottom of the images was used as reference to assign the gray tones in the spectral bands for mapping the turbidity levels.

3.3.2 Digital Techniques

The description of digital techniques are given below for mapping of water pollutants :

(i) Level slicing of each band

Systematic approach is used which involves determination of the total grey level interval for the waterbody; next dividing this interval into maximum number of equal sub-intervals. The resultant image should have contiguous regions otherwise the number of sub-intervals is reduced and process is repeated. The resultant image is colour-coded for visual interpretation.

(ii) Principal component analysis

Principal component transformation of multispectral image is carried out using data from the waterbody alone.

This is achieved by selecting suitable windows in the water body and extracting the spectral data. The first few components contain most of the variation in the data. The first component, which is usually the weighted sum of the individual bands corresponds to the total intensity received and can be correlated with turbidity. The first two components can be correlated with other water quality parameters. Qualitative turbidity level mapping can be done with level slicing of first component as described in (i)

(iii) Band ratio

Optimum band-ratio images pertaining to the waterbodies alone are generated by determining the actual maximum and minimum band-ratio values for each image and using

Table 3 : LEGEND FOR QUALITATIVE MAPPING OF TURBIDITY LEVELS IN THE MATATILA RESERVOIR USING IRS IMAGES (Source : Patel et al (1988).

Turbidity levels	S D (cm)	Turbidity (NTU)	Gray tones in spectral bands Band 1	Band 2	Band 3	Band 4
Very low	>50	<15	GB	B	DB	DB
Low	40 — 50	15 — 20	BG	GB	DB	DB
Low to moderate	30 — 40	20 — 25	G	BG	B	DB
Moderate	25 — 30	25 — 30	WG	G	B	DB
Moderate to high	15 — 25	30 — 40	WG	WG	GB	DB
High	>15	>40	WG	WG	GB	DB

DB — Dark Black　BG — Blackish Gray　GW — Grayish white
B — Black　G — Gray　W — White
GR — Grayish black　WG — Whitish gray

these to code maximum and minimum gray values of the ratio images. The ratios which are useful for water quality are B4/B1 (near infrared/green) or B1/B4, B3/B1 (near infrared/green) and B2/B1 of Landsat (red/green) MSS, respectively, for very high, moderate and low turbidity of the water. These values can be correlated with the turbidity. Qualitative turbidity levels are then mapped by level slicing as in (i) using these ratio images.

(iv) Chromaticity analysis

This technique is a quantification of the colours visually perceived, e.g. in normal colour composites or FCC's. For water quality studies the Landsat MSS bands 1, 2 and 3 are used for FCC. The bands are radiance normalised and the three grayvalues are used to calculate the brightness (value), hue (colour) and saturation (colour purity) for each pixel belonging to the water body. These coordinates are then correlated with water quality parameters.

(v) Characteristic or eigenvector analysis

In this analysis, characteristic "directions" in multispectral space are determined with respect to the clear water as origin for different water quality parameters of concentrations. These directions are determined by eigenevector analysis of data obtained from clear water and water having one parameter alone. Once the directions have been determined, the variations along each direction is then correlated with the concentration of the corresponding water quality parameter. Under the assumption of linear additive effect of water quality parameters on spectral signature, the concentration of various constituents is obtained in mixed environment.

4. Significant Results from a few case Studies

Many research workers have reported a positive relationship between the spectral signatures recorded by Landsat or airborne MSS, aerial films and water quality parameters such as turbidity, suspended sediments and chlorophyll contents (Alfoldi and Munday 1978; Lillesand et. al., 1975; Mundey et al., 1979; Ritchie and Cooper 1987; Murthy et al., 1988; Philpot and Klemas, 1981; Palria et al., 1988; Patel et al., 1988; Scherz et al., 1973). Still remote sensing of water quality in reservoirs and rivers using satellite data is of an experimental stage.

Aerial and satellite imagery can be correlated with the turbidity which, in turn, is correlated to concentration of suspended solids (Scherz et al., 1973). They have confirmed using aerial as well as Landsat imagery that the water intake from the Lake Superior, U.S.A., is turbid and unsuitable for drinking. Scherz et al have pointed out that noise effects such as skylight reflection, atmospheric effect and depth penetration also must be understood for operational use of remote sensing for water quality monitoring.

Yarger et al (1973) have examined several Landsat images of ninteen reservoirs in the Kansas State, U.S.A. They have concluded that Landsat MSS bands and ratios can be used for reliable prediction of suspended load upto 900 ppm. This conclusion is based on their earlier study (Yarger et al., 1972) where 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 images to classify lake turbidity and colour and thereby reduce the necessity for field sampling and analysis of water. In this study, the tones of 10 lakes were matched with the grey scale at the bottom of a Landsat image. This was done for each of the four MSS band images that comprise a Landsat scene. Lakes with different tones on any image were assigned to a different water class. Thus 10 lakes were divided into five classes. The authors concluded, "if a ground based sampling programme was developed, this procedure may be helpful for selecting lakes with widely differing physical and chemical qualities".

Development of the chromaticity technique started using Landsat photographic image (Mundary, 1974 a, b) and then progressed to digital analysis of computer compatible tapes (Alfoldi ahd Munday, 1978). The basis of the chromaticity method involves the transformation of radiance values from Landsat MSS bands 1, 2 and 3 into a pseudocolour plane (chromaticity space) wherein normalised brightness parameters of colour saturation and hue are examined and manipulated.

Extensive empirical testing of the chromaticity technique was conducted in the Bay of Funday on the east coast of Canada (Mundey et al., 1979). Over a period of five years, nine data sets of Landsat scenes with synchronous ground truth measurements (108 points) were collected. Eight of thess data sets were atmospherically adjusted to the ninth (the reference scene). These data were used to verify the chromaticity technique. Correlation between satellite and ground truth data for the combined data sets (after relative atmospheric adjustments) is 96 percent and the absolute error of the calibrated satellite measurements is approximately 44 percent. Effects of sediment type and size were negligible. The system can be used to measure chlorophyll, Secchi disc depth and turbidity.

A further development of the chromaticity technique for mapping suspended sediment load was developed by Lindell et al., 1986. In this, the calibration is based on several Landsat scenes from Sweden and Canada covering different solar angles. The method is continuously used for water quality surveillance of Swedish lakes.

Secchi disks are easily and commonly used as a measure of water colour and turbidity. As noted by McCuney (1975), however, Secchi depths are influenced greatly by disruption of image, caused by surface waves. There also can be significant differences in readings between observers and times of observation.

Ritchie and Cooper (1987) had analysed Landsat MSS data for 27 dates between January 1983 and June 1985 for Moon Lake in Coahoma County, Mississippi to estimate the concentration of suspended sediments by simple and multiple regression equations. The study showed that good estimates of the concentration of suspended sediments can be made using Landsat MSS data especially in the range of concentrations between 50 and 250 mg per litre.

Ritchie and Schiebe (1986) had carried out research on the remote sensing of high concentrations of suspended sediments in surface waters of an agricultural impoundment, by i) making laboratory measurements under controlled conditions using a large optical tank facility where sediment collected from Lake Chicot had been resuspended; (ii) making in-situ measurements using spectroradiometer in the Chicot lake; and (iii) using data obtained from 33 Landsat MSS scenes of Lake Chicot from the laboratory and insitu measurements, it was found that reflectance in the near infrared region, (700 to 900 nm) is significantly related to suspended sediments. The analysis of Landsat showed that MSS bands 2 (600 to 700 nm) and 3 (700 to 800 nm) radiance or reflectance were best correlated with suspended sediments.

Correlations between the relative values of the blue and green reflectance of a lake and water quality indices such as depth of photic zone, Secchi disc transparency, attenuation coefficient and chlorophyll concentration have been observed during an intensive satellite, aircraft and surface vessel study of lake Ontario and Conesus (Piech et al., 1978). They have also determined that changes in chlorophyll, ligin and humic acid concentration can be discriminated by the behaviour of the blue to green reflectance ratio and the reflectance of green and red bands.

A numerical trophic state index for lakes has been developed that incorporates most lakes in a scale of 0 to 100 (Boland et al 1979). Each major division (10, 20 etc) representing a doubling in algae biomass. Such index number can be calculated for other water quality parameters like Secchi disc transparency, chlorophyll and total phosphrous.

Multispectral scanner data (satellite and airborne) acquired over several Colorado lakes were used in conjunction with in-situ data to determine the feasibility of assessing lacustrine trophic levels (Blackwell and Boland, 1979).

A method has been developed to delineate quantitatively waste concentrations throughout waste effluent mixing zones on the basis of densitometric measurements extracted from aerial photographs (Lillesand et al., 1975). Simultaneously acquired CIR photographs and suspended-solid water samples have been used quantitatively to delineate the mixing zone resulting from the discharge of a paper mill effuent at Kimberly-clark area within the State of Wisconsin. Digital scanning microdensitometer was used to estimate and delineate suspended solids concentrations on the basis of a semiempirical model. The results indicated that aerial photography along with limited amount of ground sampling, can be used to measure and delineate the mixing-zone waste distributions more reliably and in detail than conventional surface measuring techniques.

Various sedimentation levels in the Ukai reservoir were identified using multidate Landsat MSS data (Sahai et al., 1983). Each band was analysed separately using density slicing techniques. Later on, they were superimposed on each other, such that 10 turbidity levels were identified.

Under ISRO RESPOND Programme, National Remote Sensing Agency (NRSA) have carried out water quality analysis of Hussainsagar Lake in Hyderabad and Godavari river near Rajahmundry using laboratory, field and airborne remote sensing techniques (Deekshatulu et al., 1981). Modular Multispectral Scanner (M^2 S) and multiband photography data were used. Field (boat level) experiments suggested a good correlation between turbidity, dissolved solids or colour, total suspended solids, chlorophyll, chlorides, conductivity and reflectance. Densitometric analysis of black-and-white diapositives have pointed out that polluted waters can be discriminated from clear water. Scanner data was analysed digitally on the interactive M-DAS system to produce colour - coded maps of pollution parameters.

In both the Hussainsagar lake and in the Godavari river, industrial pollution and sewage have given rise to water hyacinth, hydrilla and filamentous algae.

Under the Indian Remote Sensing Satellite Utilization Programme, a project on Water Quality Monitoring has been identified to study the water quality conditions in the inland reservoirs and lakes namely Matatila, Ramganga reservoirs and Dal, Wular, Chilka, Kolleru and Pulicat lakes in collaboration with the concerned state Govt. department/Institutes. The methodology used as well as developed in this project has been described in section 3.3. The following are some of the significant results :

Secchi disc depth distribution maps have been prepared using chromaticity analaysis technique for all test sites. Mapping of different turbidity levels and distribution of aquatic vegetation has been carried out for all the test sites.

Palria et al. (1988) studied the multitemporal Landsat image 1975 to 1986) and mapped the waterspread changes, various turbidity levels and the distribution of aquatic vegetation in the Dal and the Wular lakes. It is found that in the Wular lake the maximum waterspread is in May and minimum is in January. The changes in waterspread is significant all along the eastern margin of the Wular lake. Using colour and colour infrared photographs, pollution zones in the Dal lake have been demarcated.

Murthy et al. 1988) reported from the study of multitemporal Landsat images (1972 to 1988) of Chilka Lake that decrease in the waterspread and increase in marsh area in the Chilka lake are prominent. 6 to 8 levels of turbidity in the Chilka lake have been mapped. Medium turbidity in the Central part and high turbidity in the northern part have been observed. Patel et al. (1988) used the techniques of characteristic Vector analysis and regression analysis to quantify the relationship between the ground truth data such as turbidity and the remotely sensed data for Matatila reservoir using IRS data and also used visual techniques for qualitative mapping of turbidity levels (Fig. 1). Significant relationsphip has been obtained between IRS LISS-II data and turbidity and colour-coded map showing different concentration of turbidity levels in the Matatila has been prepared (Fig. 2 & 3). It is noted that except for the periphery of the reservoir, the turbidity in the rest of the reservoir is less than 16 NTU. The periphery shows higher turbidity (16 — 40 NTU) due to shallow water and action of waves on the bottom sediments.

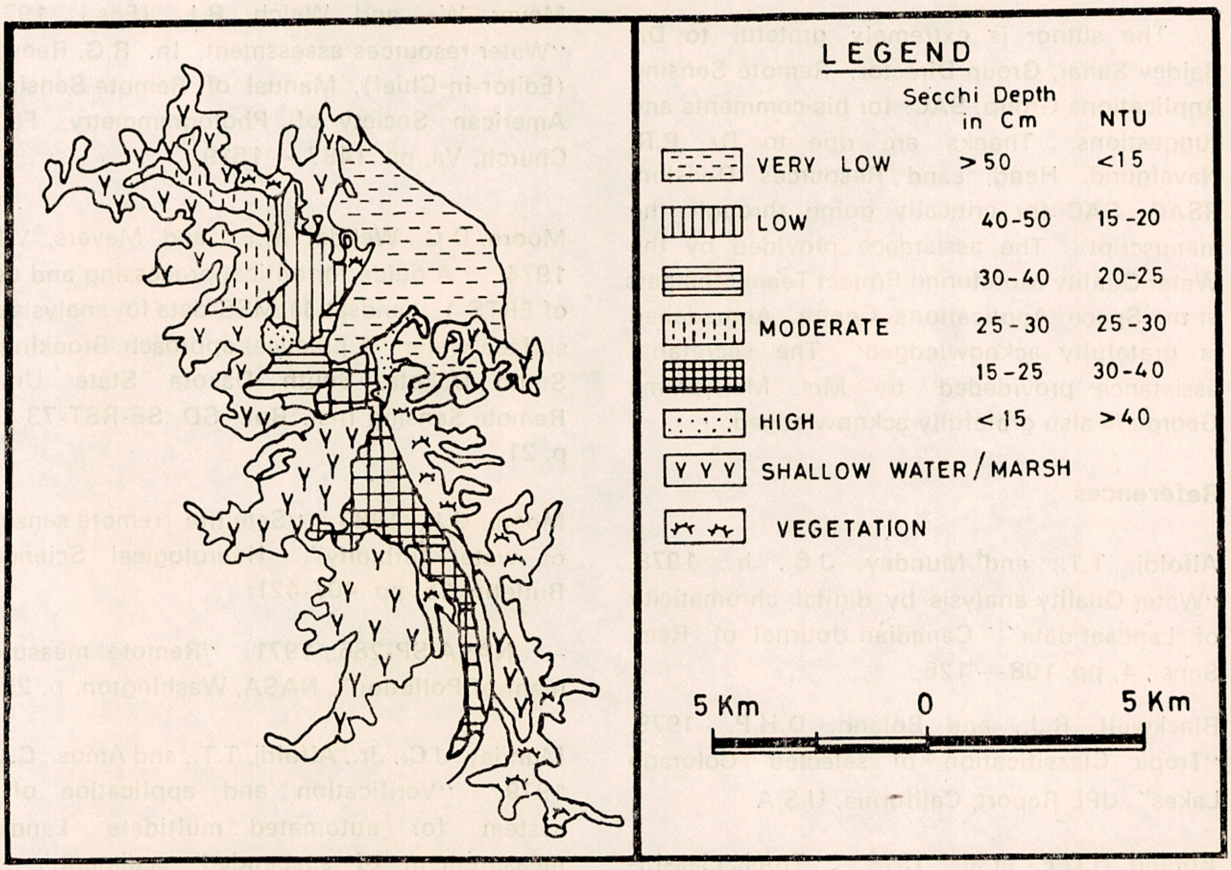

Fig. 1 Turbidity levels in the Matatila reservoir obtained from IRS Images (Bands 1 to 4) of April 27, 1988 (After Patel et al 1988)

5. Conclusions

Many experimental studies using airborne and spaceborne multiband data in conjunction with limited field data have indicated that remote sensing techniques have capability to estimate certain water quality parameters. Repetitive and synoptic coverage provided by satellite are very useful for monitoring suspended sediments, phytoplankton and sometimes waste effluents. To operationalise this technique two problems need to be solved. (i) Evolving satisfactory technique to make atmosphere corrections, and (ii) quantifying the back-scattered flux from the turbid waters. Further work needs to be done in this direction.

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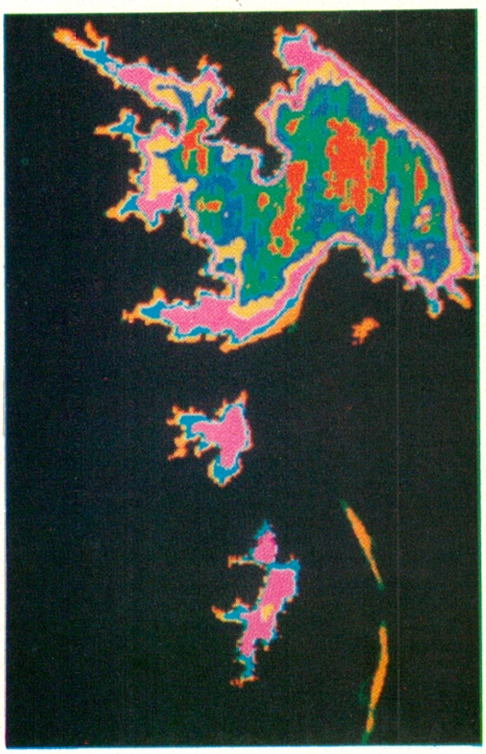
Fig. 2 IRS LISS-II FCC of Matatila reservoir
(April 27, 1988; after Patel et. al. 1988)



Colour code	NTU Range
Red	0 - 10
Green	10 - 13
Blue	13 - 16
Yellow	16 - 20
Magenta	20 - 30
Cyan	30- 40
Orange	40 - 60
Dark Green	60 - 90

Fig. 3 Colour-coded map showing Turbidity levels (NTU) of Matatila reservoir
(IRS LISS II, April 27, 1988; after Patel et. al. 1988)

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