CHAPTER I

LITERATURE REVIEW
Spectral response is a strong function of concentration and distribution of organic, chemical and solid matter in water. The variation of suspended material, concentration with depth and properties of solid matter including particles, shape, size, distribution, mineral type also influences the spectral response. The interaction of electromagnetic radiation and water body with suspended material can be indicated by one or more optical characteristics: (a) absorption (b) scattering (c) attenuation (d) Transmittance.

Jerlov (1974) presented the definition for attenuation, absorption and scattering, which can be mathematically stated as

\[ C = a + b \]

\[ b = 2\pi \int_0^\pi \beta(\theta) \sin \theta \, d\theta \]

where \( C \) = attenuation coefficient
\( a \) = absorption coefficient
\( b \) = total scattering coefficient
\( \beta(\theta) \) = volume scattering function

It can be concluded from the above equations that attenuation of water is derived from scattering and absorption. Absorption can be used instead of attenuation because scattering is negligible compared to absorption in the total wavelength spectrum except in the 0.4 to 0.5 \( \mu \)m spectral region where the
absorption or attenuation is minimal (Jerlov, 1974). The scattering of light in turbid water is primarily caused by reflection and diffraction of the incident light by suspended particles in the water (Merry, 1977). The scattering occurs at low concentration when the size of the suspended particle is small as compared to measured wavelength. The scattering of light is due to diffraction and follow Rayleigh's law which states that the reduction in the intensity of incident light is inversely proportional to the fourth power of the wavelength (Merry, 1977). The Tyndall effect occurs when a beam of light passing through turbid water illuminates the suspended particles. The illumination is caused by reflection and scattering of the incident light.

The angle of reflection of incident light will be equal to the angle of incidence. The ratio of the intensities of the incident and reflected light will be dependent on the angle of incidence between 0-90°. This can be represented by Snell's law

\[
\frac{\sin \theta}{\sin \phi} = \mu
\]

where \( \theta \) = angle of incidence

\( \phi \) = angle of reflection

\( \mu \) = refractive index

If light ray path deviates from the vertical, the ray refracted from the perpendicular at the surface when an angle of
48.5° from the verticle is reached, the ray will pass along the surface. For any angle greater than critical angle of 48.5°, the light is reflected downward. The critical angle is determined by the ratio of the velocity of light in the two medium (Merry, 1977). Scattering of light is the result of diffraction, refraction, and reflection. Particle size is the major component of light scattering. For large particles the scattering is almost independent of wavelength and depends primarily on that part of the total surface area of the particle, influenced by the light. Therefore, scattering by the large particle is not color selective. Diffraction will occur independent of the particle's composition whereas refraction and reflection will be determined by the refractive index of the particle (Merry, 1977).

According to Mie theory the particles are spherical and larger than those assumed for Rayleigh scattering with the distance between the spheres being at least three times than the radius. Also, multiple scattering does not occur. Therefore the total scattering is proportional to the number of particles (Merry, 1977). Changes in the solar elevation and in atmospheric condition can alter the magnitude of the signal and a technique of band ratioing can be used to suppress them (Bradlay et al, 1978).

In the following discussion reference to various Landsat
bands are made, however it should be kept in mind that Landsat band 4,5,6 and 7 has been renamed as band 1,2,3 and 4 in Landsat 4 and 5.

Many investigators have used Remote Sensing techniques for water quality mapping. Skylab imagery and conventional aerial photography have been used for detecting water pollution plumes and mapping sediment distribution pattern.

Stransberg (1966) pointed out that excessive concentration of plant nutrients can be interpreted indirectly by the water borne vegetation they produce which can be easily detected by the aerial photographs. Lowman (1967) used space photography to study sediment plumes and turbidity pattern within large water bodies and concluded that space photography is well suited for large water bodies, that require repetitive coverage. Schneider (1968) indicated the need of adequate ground truth data concurrent with aerial photography (low altitude) to carry out water quality mapping.

With the successful launch of Landsat 1, it was recognised by investigators that Landsat multispectral scanner provide digital radiance data which are susceptible to computerised processing in large volume and can also be used for quantitative estimation of suspended sediment and other water quality parameters which was not possible by photographic data (Whitlock, 1977). Klemas et al. (1973), recommended capability of
Landsat multi spectral scanner to detect sediment plumes and aquatic fronts with band 5. Wezernak et al. (1973), recommended that airborne or landsat multi spectral scanner has the ability to detect acid iron wastes, sewage sludge, suspended solids and major water mass boundaries in the New York Bight area.

Grew (1973) concluded that it was feasible to distinguish between algae and sediment from tests conducted at Clear lake, California. Blanchard et al., (1973) used spectroradiometer for insitu measurements and observed that measurement of suspended sediment in water is feasible upto concentration 75 mg/l depending on color and source of sediment. Scherz et al. (1973), indicated that influential factors are surface reflection of sun, atmospheric scatter, surface reflection of the sky and bottom effect to be incorporated in the analysis of volume attenuation measurements of various water samples and concluded that upwelled radiance positively correlates with water turbidity. Yanger et al. (1973), also indicated that sun angle had a significant effect on upwelled radiance signals and formulated a band ratio technique which nearly suppressed the effect of unequal illumination. They defined:

\[
\text{Rad}_X = C + JK
\]

\[
\text{Rad}_Y
\]

Where \( C \) = water constituent concentration
Rad X = radiance at wavelength X
Rad Y = radiance at wavelength Y

It was also reported that band ratio techniques eliminate the effect of variable atmospheric scattering and absorption for concrete target on the ground, however band ratio algorithm did not produce consistent result for experiment conducted on different days. Later Yarger et al. (1975), correlated 16 landsat overpass over three kansas reservoirs with 170 water samples and found the band ratio type of algorithm depressed the effect of seasonal sun angle variation and that suspended solids could be quantified with a linear algorithm to a standard error of 12 ppm over a range of 0 to 80 ppm suspended solids. They found that the radiance-concentration relationship was nonlinear for concentration above 80 ppm, however the correlation studies with skylab MSS produces similar results upto 100 ppm. Ritchie et al. (1975) also indicated that sun angle has an effect on correlation of upwelled radiance to suspended solids. The wavelength range between 550 to 600 nm provided the optimum sensitivity for irradiance measurements. The water depth that permits detection of the bottom of water body depends on water colour, turbidity, bottom characteristics and intensity of incident light.

McCaeley (1977) made extensive study of Kansas reservoirs
using Landsat and Skylab data and observed that band 4 & 5 (green and red) are correlated with suspended solids concentration upto 50 to 800 ppm respectively, band 6 show good correlation upto 240 ppm and band 7 show some response to high turbidities. The results of the study indicate that band ratio have the effect of greatly diminishing the influence of sun angle. MSS 5/MSS 4 and MSS 6/MSS 4 have good linear fit for turbidity of 80 and 100 ppm respectively and ratio of MSS 6/MSS 4 and MSS 7/MSS 4 both appear to increase with increasing turbidity upto 900 ppm. It has also been noted that Skylab sensor S-190A and S-192 gave results roughly comparable to those achieved using landsat MSS.

Holmquist et al., (1977), developed linear regression equation in conjunction with ground truth and concluded that satellite data could be used for prediction of lake water parameter or tropic classification. It has also been indicated that data from larger lake and periodic survey is needed for high reliability in prediction of tropic state.

Moore (1978), correlated aircraft spectroradiometer data with concurrently obtained field measurement of percentage of transmittance surface temperature, pH and secchi depth. In addition electron micrographs and suspended sediments concentration data were also obtained. On the basis of his observations, it can be concluded that:

(a) Secchi depth measurements is inversely proportional to the
radiance measured by spectroradiometer.

(b) As transmittance of water decreased the reflected radiance increased.

(c) As insoluble particulate concentration increased, the reflected radiance increased in the range of 1-80 ppm.

(d) The reflected radiance in the near infra-red region (0.76-0.9 μm) always increased as insoluble particulate matter concentration increased.

(e) The peak reflected radiance varied with the insoluble particulate matter concentration:

<table>
<thead>
<tr>
<th>Peak Reflected Radiance (mW/cm²-Sr)</th>
<th>Concentration (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0001-0.0027</td>
<td>1-5</td>
</tr>
<tr>
<td>0.0027-0.0047</td>
<td>5-44</td>
</tr>
<tr>
<td>0.0047-0.0060</td>
<td>44-77</td>
</tr>
</tbody>
</table>

He has also discussed about the variable that can affect remote sensing of physical water quality characteristics. For clear and shallow water bodies the solar energy is reflected from the bottom. The water depth that permits detection of the bottom depends on water colour, turbidity, bottom characteristics and intensity of incident light. In clear deep water near infrared light is absorbed up to a depth of 20 cms, and red light within 2 meters of the surface. Blue and green wavelengths penetrate more
than 20 meters. About 50 percent of the signals of blue light (0.4-0.5 μm) comes from a depth of 15 meters but for red light (0.6-0.7 μm) most of the signals comes from a depth of less than 1 meter.

Cochrane et al., (1978), noted that contrast enhancement procedure provide verification of broad pattern of suspended sediment distribution. However, satisfactory results were obtained by them using maximum likelihood classification.

The regression analysis is a technique in which the radiance value of different wavelength (on bands) are correlated with ground truth concentration values of a particular parameter in a linearised least square fit manner. When a high value of coefficient of determination, low value of a standard error and F value at least 4 times the critical value is obtained, then the regression equation obtained from the least square fit can be used to estimate water constituent concentration in other areas where no ground truth measurements are available.

Whitlock, (1977) examined the limitations, requirement and precision of the linear multiple regression technique for quantification of water quality parameter from remote sensing data. From laboratory results it was concluded that effect of error in upwelled radiance measurements was to reduce the accuracy of the least square fitting process and to increase the number of points required to obtain a satisfactory fit. It has
also been concluded that the linearised multiple regression is applicable in situation in which some types of optical interaction occur between constituents day coverage provided by the 14% overlap in the landsat sensor scan path, which may have discrepancy related problems. The overlap provides opportunity to essentially come back the next day and verify results or conclusion drawn from previous day. Lodwick (1978) pointed out errors between 51 to 97 metres in misregistration between seven landsat scenes due to seasonal changes, which made identification of control from scene to scene variable over the whole sequence. For a reliable comparison of change in reflectance from one scene to another a minimum 3 pixel square is required. Kuo et al. (1978), investigated the properties of the suspended material, factors influencing the upwelling radiance and the various types of remote sensing techniques. Calibration and correlation procedure are also given by them to obtain the accuracy necessary to quantify the suspended materials by remote sensing. In addition they have also given detailed recommendation for laboratory and insitu measurement required for remote sensing of suspended material. Later Duggin, (1980) simultaneously measured irradiance and reflected radiance with two radiometers and the sun angle dependence achieved from a measurement of local time of observation. It is recommended that it is essential to measure
irradiance and radiance simultaneously to avoid error in reflectance factor due to irradiance changes arising from atmospheric fluctuation which can occur between sequential measurements.

Mckim et al. (1984), used 500 channel spectroradiometer for monitoring the suspended load in lakes, reservoir and waterways. Field and laboratory experiments were conducted to test and evaluate the radiometer response up to a limit of 100 mg/l of organic matter in shallow water. The spectral distribution of clay-algae suspension was consistent with the data of individual clay and spectra.

Khorram (1981 and 1982), used Landsat MSS digital and airborne ocean color scanner data for chlorophyll, turbidity, suspended solids and salinity mapping by means of digital processing in San Francisco bay-delta. Concurrently collected airborne ocean color scanner data and surface truth measurements were also used. Regression models were developed between each of the water quality parameter measurements and mean radiance value for 29 sample sites. These models were then extended to the entire study area for mapping of water quality parameter using simple linear discriminant function by applying this function to each pixel in the study area. The grouping of these continuous water quality variables into discrete classes were made. The concept was again applied to Landsat data in his (Khorram, et al.,1985) later
experiment in the Neuse estuary in which 75 surface water samples were collected concurrent with landsat overpass, from sites greater than 10 feet depth to avoid bottom noise component. Sampling was done between 8.45 to 9.50 a.m. Regression models were developed between each of the water quality parameter and MSS digital data for 46 sample sites. The best regression fit for each one of the selected water quality parameter was determined based on coefficient of determination, F value, significance level of F value, residual value and simplicity of model. The coefficient of determination for best model were observed to be high for salinity, relatively high for chlorophyll and medium for suspended solids.

Salinity model

\[ Y_{SAL} = a - bx \]

where \( Y_{sal} \) = Salinity in part per thousand

\[ x = Band 6/(Band 4 + Band 5) \]

\[ a = 38.52 \text{ and } b = 120.86 \]

Chlorophyll model

\[ Y_{LCH} = a + bx + cx - dx \]

where \( Y_{LCH} \) = The natural log of chlorophyll a concentration expressed in \( \mu g/l \)

\[ x = Band 4/Band 5 \]

\[ a = 38.52 \text{ and } b = 120.86 \]
\[ x = \frac{\text{Band 4}}{\text{Band 5} + \text{Band 6} + \text{Band 7}} \]

\[ a = 2.14, \quad b = 5.19, \quad c = 0.01 \quad \text{and} \quad d = 7.74 \]

**Turbidity model**

\[ Y = -a + bx - cx + dx - ex \]

**TURB** 1 2 3 4

where \( Y \) = Turbidity expressed in Nephelometric turbidity unit.

\[ x = \frac{\text{Band 4} - (\text{Band 5 x Band 7})}{(\text{Band 5} - (\text{Band 6 x Band 7}))} \]

1

\[ x = \frac{\text{Band 4}}{\text{Band 6}} \]

2

\[ x = \frac{\text{Band 4}}{(\text{Band 4} + \text{Band 5} + \text{Band 6})} \]

3

\[ x = \frac{(\text{Band 4} - (\text{Band 5 x Band 6}))}{(\text{Band 5} - (\text{Band 6 x Band 7}))} \]

4

\[ a = 4.54, \quad b = 0.09, \quad c = 0.43, \quad d = 21.9, \quad c = 0.03 \]

**Suspended Solid Model**

\[ Y_{ss} = a - bx + cx + dx + ex - fx + gx \]

1 2 3 4 5 6

where \( Y_{ss} \) = Suspended solids expressed in mg/l

\[ x = \frac{(\text{Band 4} - (\text{Band 5 x Band 7}))}{(\text{Band} 5 - (\text{Band 6 x Band 7}))} \]

1

\[ x = \frac{\text{Band 5}}{\text{Band 6}} \]

2

\[ x = \frac{(\text{Band 5} - \text{Band 6})}{(\text{Band 6} - \text{Band 7})} \]

3

\[ x = \frac{\text{Band 5}}{(\text{Band 4} + \text{Band 5} + \text{Band 6})} \]

4

\[ x = \frac{(\text{Band 6} / \text{Band 4}) + (\text{Band 5} / \text{Band 6})}{(\text{Band 4} - (\text{Band 5 x Band 6 x Band 7}))} \]

5

\[ x = \frac{(\text{Band 4} - (\text{Band 5 x Band 6 x Band 7}))}{\text{Band 5}} \]

6

\[ a = 285.85, \quad b = 1.22, \quad c = 85.80, \quad d = 2.47, \quad e = 1203.36, \quad f = 439.21, \quad g = 0.19 \]
Khorram et al. (1985), recommended that Landsat TM data may produce better results for Chlorophyll and turbidity due to improved spatial (30m), spectral (7 channel) and radiometric (8 bits) characteristics. Particularly lower wavelength may be more useful. It has also been recommended that further laboratory analysis of suspended solids along with radiometric data for identification of suspended material contribute most to the spectral response.

The principal component analyses 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 variable identical in number to the original ones are linearly independent. The total variance calculated for the scores is identical to the variance in the original bands. However, there is a high correlation between original bands of landsat. The first and second principal component (PC 1 & PC 2) typically account for more than 95% of the original variance mostly land and vegetation (Lodwick, 1978).

Lodwick et al. (1985), used principal component analysis (PCA) technique to compare the landsat data with water quality statistics for lake Athabasca. PCA were carried out on 11 field data set and the 4 landsat band. The linear regression parameter was calculated for 4 combination of raw and PCA data sets. Their results indicated that PCA technique has potential
as an analyses tool to depict sedimentation in water bodies. The correlation coefficient was 0.8 which shows 64% suspended sediment information contained in PC 1. PC 2 (band 4 and band 5) did not correlate, PC 3 correlated well with conductivity at the surface.

Amos et al. (1985), were the first to correlate coastal zone color scanner sensor (CZCS) to lithic suspended particulate matter in Bay of Fundi. They concluded that log (SSC) and channel ratio (3:5) of CZCS have good correlation (R = 0.92; n=10) with sediment concentration in the range of 10-165 ppm. Band 4 saturate above 5 ppm at gain setting of 1(low), hence chromaticity techniques to CZCS data cannot be applied. The chlorophyll together with other sources caused high degree of scatter at sediment concentration below 10-20 ppm.

Significant contribution was made by the Ritchie et al. (1974, 1975, 1976, 1986, 1987 and 1988) in the estimation of suspended sediment concentration with remote sensing technique. First study was made (Ritchie et al., 1974) using spectrometer measurements in six Mississippi lake. They observed high linear correlation coefficient (r = 0.90), between upwelled radiation and total suspended solid in the 28 to 242 ppm range. It was later found (Ritchie et al., 1975) that sun angle had an effect on the correlation of upwelled radiance to total suspended solids. Ritchie et al. (1986), conducted laboratory measurements under
controlled condition by resuspending sediments collected from lake Chikot and insitu measurements using hand held spectroradiometer over surface of lake Chikot, followed by analysis of 33 Landsat MSS scene. Their laboratory and insitu measurements showed that reflectance in infrared region (600 to 900 nm) is significantly related to suspended sediment concentrations, greater than 100 ppm. The analysis of MSS data indicated that band 5 and band 6 are best correlated with suspended sediments. It has also been noted that radiance tended to become saturated at lower wavelength as suspended sediment concentration increased. Later Moon lake of Mississippi river was selected to (Ritchie et al., 1987) evaluate the use of MSS digital data for estimating suspended sediment concentration. Surface water samples were collected on 63 different days at 5 sample sites (June 1982 to June 1985) nearer to landsat overpasses. Landsat MSS spectral bands were extracted for 5 x 5 pixel array surrounding each 5 sample sites. Average pixel value were then converted into radiance, reflectance and scene corrected values (Pixel value−minimum pixel value − 1). These values were then used in the regression analysis. It was concluded that pixel value and concentration less than 200 ppm of suspended sediments were linearly related. At higher concentration relationship became nonlinear. Total dissolved solids also gave similar results. The band 3 provided the best estimates of concentration of suspended sediments.
sediment in surface water. Pixel values corrected for the minimum pixel value gave the best results. The multiple regression techniques using two or three bands showed improvement in results. The remaining 13 cloud free Landsat scene between Jan 83 and June 1985 were analysed later (Ritchie et al., 1988). The comparative results showed that high estimated values were observed at low concentration and low estimated at high concentration. They concluded that the results would have been better if field data had been taken on the same date of Landsat overpass. The intercept was greater than zero at low concentration equation overestimated suspended sediment concentration and underestimated the higher concentration. It was further concluded that good estimate of suspended sediments concentration between 50 to 250 ppm can be made with simple regression equation based on Landsat MSS data. Equation used to estimate suspended sediment concentration was:

**MSS Pixel data**

ESS = -51.4 + (4.1 * MSS Band 2)

ESS = 99.8 - (10.9 * MSS Band 1) - (3.0 * MSS Band 2) +
   (12.9 * MSS Band 3) - (7.8 * MSS Band 4)

**MSS pixel corrected data**

ESS = -25.2 + (6.9 * MSS Band 3)

ESS = -34.9 + (2.4 * MSS Band 1) - (6.9 * MSS Band 3) -
   (3.6 * MSS Band 4)

Radiance based on MSS pixel data
ESS = -65.1 + (317.9 * MSS band 3)  
ESS = 92.4 - (516.0 * MSS band 1) - (135.8 * MSS band 2)  
+ (1345.2 * MSS band 3) - (389.9 * HSS band 4)

Radiance based on MSS pixel corrected data

ESS = -46.0 + (590.4 * MSS band 3)  
ESS = -46.3 + (148.6 * MSS band 1) - (573.6 * MSS band 3) - 133.7 * HSS band 4

Reflectance based on MSS pixel data

ESS = -138.5 + (2025.9 * HSS band 3)  
ESS = 33.5 - (1443.0 * MSS band 1) - (4336.2 * HSS band 3) - (2668.8 * MSS band 4)

Reflectance based on MSS pixel corrected data

ESS = -73.3 + (2020.9 * HSS band 3)  
ESS = -124.0 - (709.2 * MSS band 1) - (1578.3 * MSS band 3)  
+ (1984.0 * HSS band 4)

Where ESS = estimated suspended sediment (ppm)

Jensen et al. (1989), used atmospherically corrected chromaticity data derived from Thematic Mapper to develop models for salinity and suspended solids for two dates (25 Nov. 1984 and 24 April 1987). These models were then compared with numerical models. It was concluded that suspended solids map at 1.5 x 1.5 km resolution may give a correlation map useful for identifying areas of discrepancy between remotely sensed data and model output. It was also concluded that the technique is feasible for estimating and predicting circulation and dispersion
characteristics in coastal lagoon/estuarine system where long time hydrographic data are unavailable. Doerffer et al. (1989), also used TM data for mapping of suspended matter distribution in the coastal area of the German Bight (North sea). Factor analysis techniques were applied to extract information on suspended matter concentration, atmospheric scattering and sea surface temperature. It was concluded that TM data are very useful for mapping suspended matter concentration in highly structured area such as the coastal zone with tidal flats and sandbank.

Novo et al. (1989 a and b), conducted laboratory experiments under controlled environment to understand the effect of viewing geometry and wavelength on the relationship between reflectance and suspended sediment concentration. They concluded that there is a positive relationship between reflectance and suspended sediment concentration, which varies with wavelength and viewing geometry. It was also concluded that the visible (0.55 and 0.65μm) and near infrared (0.75μm) wavelengths are best for sensing of suspended sediment concentrations. They have also observed that sediment type can affect the relationship between SSC and reflectance especially in shorter wavelength.

In the last few years an enormous amount of development in usage of remote sensing techniques in the field of natural resources such as Geology, hydrology, forestry, agriculture etc. has taken place in India. However very limited work has been done
in the water quality mapping and sediment in river, reservoir, lakes and estuarine systems.

Rao et al. (1978) studied spectral signatures of water bodies having relative turbidities from 3 to 25 and corresponding spectral reflectance values. Ground data were correlated with concurrently acquired aircraft modular multispectral scanner data. They concluded that the spectral reflectance increased much faster in lower turbidity value and absorption of radiation in water was of exponential nature.

Deekshatulu et al., (1981) have carried out water quality mapping of Hussainsagar lake in Hyderabad and Godavari river near Rajamundry using laboratory, field, and airborne MSS and multi band photography. Field experiments indicated high correlation between turbidity, dissolved solid, total suspended solids and chlorophyll. Their densitometric analysis showed that polluted water can be discriminated from clear water. Color coded maps of water quality parameters were produced using M.DAS image processing system.

Thiruvengadachari et al., (1983 a) conducted insitu spectral measurement and collected water samples simultaneously with airborne 11 channel MSS overpass in Godavari river. They observed that secchi depth does not correlate with turbidity and suspended sediment. This indicated that the relationship between secchi depth and back scattered energy must be essentially due to color.
The good correlation between secchi depth with dissolved solid and with chlorides confirmed the influence of color on back scattered energy. Nayak (1983) applied band ratioing and dark object substraction techniques for correcting atmospheric effect. He found the ratio of MSS 6 / MSS 4, MSS 7 / MSS 4 and MSS 5 / MSS 4 is suitable for estimation of suspended sediment having low to high and low concentration respectively.

Thiruvenkadachari et al., (1983 b) outlined the ground data requirement, depth of sampling, time lag, location of sampling sites, elimination of spectral noise component and planning of redundancy in ground truth, water sample collection, preservation, storage and analytical methods.

Muley et al., (1986 a) visually interpreted multiday, multiband landsat images of Wular, Dal, Chilka lakes and Rihand reservoir and indicated that Band 4 & 5 gives better information about turbidity levels present in water column and the compilation of all band is essential to achieve optimum level of turbidity. Muley et al., (1986 b) conducted a spectral signature experiment with fine and coarse loam to measure the reflectance under controlled conditions. They concluded that variation in turbidity can be distinguished using spectral data. Optimum bands for the study of turbidity were 448-532 nm, 572-565 nm, 505-607 nm, 624-697 nm and 712-799 nm, which depend on the nature, size and concentration of suspended materials.
Rampal et al. (1989) developed a regression model between suspended solids and Landsat data for Krishna delta. It was concluded that Landsat digital data can be used successfully for suspended sediment mapping.

Considering all the above discussions and investigations, it can be concluded that it is possible to use digital spectral data from the Landsat MSS to estimate the concentration of suspended sediment in the surface water of lakes and reservoir. Various types of algorithms have been attempted by investigators. Simple linear and multiple regression analyses techniques are judged to be most reliable process (Whitlock 1977, 1982, Khorram et al., 1985, Ritchie et al. 1987, 1988), for quantitative estimation of suspended sediments and other water quality parameters. Additional laboratory analyses of suspended solids along with multiband radiometric data may be used to identify those suspended materials which contribute most to the spectral response (Khorram et al. 1985). Selection of ground truth locations to maximise variance is recommended to minimize data smoothing requirements and physical errors associated with that process. No time lapse between remote sensor overpass and water sample collection is recommended (Whitlock et al., 1982).

For the purpose of application of remote sensing techniques to quantify the suspended load and other water quality parameters in an inland water body in India, Tawa reservoir located in the
Narmada basin in central India (M.P) has been selected.

The field sampling, details of which are given in the later section, was carried out in the months of September and October 1988 concurrent with IRS overpass. IRS-LISS1 computer compatible tapes were purchased from National Remote Sensing Agency, Hyderabad. The details of IRS, study area, methodology, results are discussed in the following chapters.