REMOTE SENSING AND WETLANDS – REVIEW

Satellite remote sensing is a very useful technique for inventorying, mapping and monitoring of wetland ecosystems due to its synoptic coverage, multispectral character and repetitive nature. Due to these features the technology has proved its value in providing a firm basis for sound ecological management of wetlands. Studies have been carried out using orbital remote sensing for monitoring water spread, turbidity/siltation, aquatic vegetation infestation, and trophic status of various inland and coastal ecosystems. In addition, satellite data have also been used in quite a few studies to map and monitor industry induced pollution. Remotely sensed data has also found its use in aiding sewage treatment plant site selection as a measure for pollution abatement in the rivers. However, despite so many advantages the technology offers remote sensing has been used in a very few studies for inventory of wetlands at national or regional levels.

PHYSICAL BASIS OF REMOTE SENSING OF WATER

The depth, suspended sediments, water colour, sun-elevation angle, atmospheric conditions and time of the year mainly govern interaction of EMR (electromagnetic radiation) with water. The solar energy interaction with water bodies can be described as below (Moore, 1980):

\[ I_o = I_{SR} + I_A + I_B, \]

where

\[ I_o = \text{Solar energy reaching the water surface} \]
\[ I_{SR} = \text{Solar flux that is specularly reflected at the water surface} \]
\[ I_A = \text{Flux absorbed by water} \]
\[ I_B = \text{Flux backscattered to the water surface and thereby available for remote detection} \]
As mentioned earlier, the mechanism of absorption, scattering and reflection is selective and depends on the physical and biological characteristics of the water mass. In shallower and turbid waters bottom reflectance and suspended solids affect the signal to a great extent and it is not possible to separate the signals from bottom and suspended sediments. Only the light, which has penetrated the water column and reaches the surface again has the information about water quality parameters. The signals are also modified by the intervening atmosphere, which may cause attenuation or accentuation. It may be mentioned here, that blue light causes more scattering in comparison to red light.

**SPECTRAL PROPERTIES OF WETLANDS**

As already mentioned in earlier chapters, driving features of wetlands are water, hydrophytic vegetation and hydric soils. Consequently, wetland signatures are a manifestation of various permutations and combinations of the above depending on the quantum and quality of each present in a particular wetland. Spectral response of the wetlands has to be interpreted in a three dimensional model. Wetlands exhibit differing signatures in different parts of wetland depending on:

- Water depth or column, and suspended material in water
- Ecological characteristics of vegetation such as prevalence of planktons; floating, emergent or submerged vegetation.
- Age of the vegetation especially emergent and floating.

**Spectral response and Suspended material**

Water depth and suspended material plays a significant role in determining the manifestation of spectral response from the water mass. The water column absorbs most of the radiation in the near infrared (NIR) and middle infrared (MIR) regions. It is this property of water due to which even very small
water bodies/wetlands are possible to detect. In the visible part of EMR, total reflectance from the water body depends on the reflectance from the water surface, bottom material and other suspended material present in the water column. Turbidity in the water generally leads to increase in its reflectance and the reflectance peak shifts towards the longer wavelengths. Fig. 3.1 gives graphically relationship among reflected solar radiation, wavelength, and the concentration of total solids in surface waters as studied by Ritchie et al (1974). It was demonstrated by them that solar radiation was best correlated \((r = 0.90)\) with the concentration of total solids in the surface waters at wavelengths of 0.75 and 0.8 \(\mu\)m. It was also shown that the ratio of reflected solar radiation to incident solar radiation was also best correlated \((r = 0.87)\) with the density and concentration of total solids in the surface waters at 0.8 \(\mu\)m. They have also found that the correlation coefficient for concentration of total solids in the surface waters with reflected solar radiation was greater \((r = 0.87)\) for the 0.7-0.8 \(\mu\)m range than for the 0.6-0.7 \(\mu\)m range.

**Response of water bodies in the presence of Vegetation**

In general, vegetation has a typical high reflectance value in the near IR though these values differ significantly depending on the species and the background. Pfieffer et al (1973) have studied the spectral response of Spartina alterniflora, common vegetation in salt marshes of USA. It was found that the community reflectance of tall \(S.\ alterniflora\) was higher in the visible range and almost twice as high in the near IR in contrast to intermediate height stand of same species. They have partially ascribed this to the presence of stands of wider leaves in creek bank. Reflectance values were lower in the short stand than in the tall \(S.\ alterniflora\) community, probably due to the lower biomass and vertical leaf orientation.

Scherz (1977) has studied satellite (Landsat) residual signal for clear-type water lakes having various amounts of algae (Fig. 3.2). Depending upon the amount of algae it was possible to differentiate between various lake types. It
FIG. 3.1: RELATIONSHIP AMONG REFLECTED SOLAR RADIATION, WAVELENGTH, AND THE CONCENTRATION OF TOTAL SOLIDS IN SURFACE WATERS (Ritchie et al, 1974)
FIG. 3.2: SATELLITE RESIDUAL SIGNAL $R_i$, FOR CLEAR-TYPE WATER LAKES WITH VARIOUS AMOUNTS OF ALGAE (Scherz, 1977)
proved that the chlorophyll present in the lakes plays a significant role in determining the spectral response.

WETLAND ECOSYSTEMS AND REMOTE SENSING

Remote sensing data has been mainly utilised either for delineating wetlands and mapping internal composition or for estimating biophysical and biogeochemical properties. Table 3.1 gives wetland information needs which can be obtained today or in near future using satellite remote sensing.

Table 3.1: Wetland ecosystems: assessment and monitoring needs

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Spatial resolution (m)</th>
<th>Radiometric resolution (bits)</th>
<th>Spectral regions/ bands (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Morphometric parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Areal extent, type, dynamics</td>
<td>10-20</td>
<td>8</td>
<td>0.42 - 0.52</td>
</tr>
<tr>
<td>Avi-fauna habitat suitability</td>
<td></td>
<td></td>
<td>0.53 - 0.59</td>
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<td></td>
<td></td>
<td></td>
<td>0.63 - 0.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.77 - 0.86</td>
</tr>
<tr>
<td>Hydrophytic vegetation, type, trophic status, eutrophication</td>
<td>5 - 20</td>
<td>8</td>
<td>0.42 - 0.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.63 - 0.69</td>
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<td></td>
<td></td>
<td></td>
<td>0.77 - 0.86</td>
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<td></td>
<td></td>
<td></td>
<td>1.55 - 1.75</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>2.08 - 2.35</td>
</tr>
<tr>
<td><strong>B. Pollution</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Pollution sources/waste out fall</td>
<td>1 - 5</td>
<td>8</td>
<td>0.53 - 0.59</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>0.63 - 0.69</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>0.76 - 0.86</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>3.66 - 3.84</td>
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<tr>
<td></td>
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<td>3.93 - 3.98</td>
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<td></td>
<td></td>
<td></td>
<td>10.78 - 11.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11.77 - 12.27</td>
</tr>
<tr>
<td>Turbidity, sediments and suspended solids</td>
<td>30</td>
<td>8</td>
<td>0.56 - 0.58</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>0.64 - 0.66</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>0.74 - 0.78</td>
</tr>
<tr>
<td>Phytoplanktons/ algal blooms</td>
<td>30 - 50</td>
<td>8 - 10</td>
<td>0.510 - 0.530</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>0.555 - 0.575</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>0.620 - 0.640</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>0.660 - 0.670</td>
</tr>
<tr>
<td>Thermal pollution</td>
<td>5 - 10</td>
<td>8 - 10</td>
<td>3.66 - 3.84</td>
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<tr>
<td></td>
<td>0.5°C</td>
<td></td>
<td>3.93 - 3.98</td>
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<td>10.78 - 11.28</td>
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<tr>
<td></td>
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<td></td>
<td>11.77 - 12.27</td>
</tr>
<tr>
<td>Oil pollution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water pollutants and biophysical parameters (BOD, COD, DO, etc.)</td>
<td>50 - 100</td>
<td>10</td>
<td>Sensors yet to be developed</td>
</tr>
</tbody>
</table>

Unfortunately, orbiting satellites do not provide information on many of the parameters listed in the table.

DETECTION AND DELINEATION OF WETLANDS ON THE SATELLITE IMAGERY

Conventional way of delineating wetland boundaries in the field are cumbersome and inaccurate. It has been found that remote sensing data is better suited for delineation of wetland boundaries (Garg et al, 1998). It is, as mentioned in the preceding section, due to the low-level radiance values of water in the near IR region. On a False Colour Composite (FCC) water part of wetland shows up in various hues of blue depending on the depth of the water column and suspended material. Vegetation if totally covering the water surface (as for example water hyacinth mats) appears pinkish red while emergent and submerged appear in brownish red colour depending on the extent of background water exposure, condition and age. In addition to this, watermark impression can also be picked up easily on the satellite imagery that helps in setting the boundary of the wetlands.

MAPPING AND MONITORING OF WETLANDS-TECHNIQUES

Both visual and digital analysis techniques have been used for the study of wetland ecosystems. Mapping and monitoring of wetland ecosystem presupposes the usage of temporal satellite data. The main considerations in the selection of data are:

i) Remote sensing data of a proper season should be selected to study the wetland parameters. As for example, for finding out the presence or absence of aquatic vegetation, pre-monsoon data is better. Similarly, for turbidity assessment post-monsoon and pre-monsoon sequential imagery may be required.
ii) For monitoring purposes, temporal data (from same or different satellites) should be of the same season and preferably of nearby dates.

iii) The multidate data should be accurately registered either with respect to each other or to the available topographical maps.

In case of analysis of temporal digital data appropriate corrections should be applied for changes in sun angle, sensor parameters (gain, bias etc.) and the shift in the reflectance caused due to atmospheric scattering.

The scale of mapping for inventory depends on the objectives and the level at which the inventory is desired viz. national, regional or local, smallest area to be mapped, availability of funds, trained manpower and the urgency. For example, for national inventory of wetlands, a scale of 1:250 000 or 1:50 000 may be adequate. For detailed investigations scales of 1:50 000 and 1:25 000 or larger are appropriate. Accordingly, the satellite data, season and its format are chosen. For inventory, use of at least one satellite data set pertaining to both post-monsoon and pre-monsoon seasons is desirable.

**Visual Analysis**

Visual analysis techniques are better suited for wetland inventory (Garg et al, 1998). Base maps are prepared using topographical maps of the same scale (Survey of India). Prominent and features like rivers/streams, roads, and other major settlement are marked onto the base maps as these serve as controls while doing interpretation. Base maps can be prepared SOI topographical map-wise, basin-wise or district-wise. Subsequently, analysis/interpretation of satellite data is done on these maps. For better accuracy, ground truth data is collected and correlated with tonal variations in the aquatic ecosystems as observed on the imagery.
**Digital Analysis**

Digital analysis techniques are normally deployed to make full use of radiometric and spectral information available in the imagery. Moreover, many a times digital analysis is also carried out in case of rivers/streams whose width is very narrow and pixel-wise analysis can bring out the stretches affected by pollutants. Digital analysis of satellite data has not found much use for inventorying and monitoring at operational levels primarily due to overlapping of spectral signatures (many a times), high cost, image processing facilities and time constraints. However, digital analysis techniques coupled with conventional field data do have the potential for wetland inventory, monitoring and assessment of physical parameters like turbidity, aquatic weed infestation, Sechhi disc transparency etc.

In the analysis of remotely sensed data an analyst should always consider resolution, sensitivity (sensor capability to differentiate the spectral response between targets) and dynamic range (minimum to maximum range of reflectance measured by the sensing device) of the sensor system. Resolution again may be spatial (sensor capability to discriminate the smallest object on the ground), spectral (spectral interval or wavelength bands in which data is acquired) and temporal (repetitivity or revisit period).

**WATER QUALITY OF WETLANDS**

Water quality studies have conventionally been carried out using *in situ* measurement of various pollutants. Remote Sensing for water pollution started with the measurement of spectral response of water bodies artificially polluted under controlled conditions and their subsequent correlation with radiance/reflectance values. However, the studies could not be extended to orbital altitudes due to non-availability of specific sensors onboard various remote sensing satellites. Broadly, satellite remote sensing allows detection
and mapping of sediments, changes in colour and temperature variations in aquatic ecosystems.

**Visual Analysis**

For water quality monitoring base maps are prepared at an appropriate scale (1:50 000 or 1:25 000) depending on the objectives. In addition, all pollution carrying channels/waste outfalls etc., if any, are also marked. On the enlarged FCC photo prints, various polluting sources (waste out-falls/open drains, natural drainage etc.) are identified. Also, industries such as thermal power plants, fertiliser plants, smelters, and mining areas etc., if they are present, are marked.

Once the sources and their effluent carrying channels are identified any tonal variation in water is noted and checked in the field/with available water quality data. With the help of elements of image analysis and *a priori* knowledge of the interpreter, preliminary maps for turbidity, aquatic vegetation infestation etc. are prepared. These maps are further characterised in respect of various water quality parameters during the next satellite pass. The above method is mainly useful for monitoring coloured pollution load.

**Digital Analysis**

As mentioned earlier, digital analysis techniques are normally deployed to make full use of radiometric and spectral information available in the imagery and in case of rivers/streams whose width is very narrow. Some of the techniques are image enhancements, band ratioing, density slicing, principal component analysis, image differencing, chromaticity analysis and post-classification comparison.
i) Image Enhancements

These techniques are applied to remotely sensed data for improving the appearance of a low contrast image. This facilitates the analysis using visual methods. Normally, linear and non-linear contrast expands the image to cover the entire brightness ranges while the later makes use of user specified brightness range.

ii) Band Ratioing

Band ratios are quite useful in separating physical classes in a water mass. Simple band ratios (IR/R, IR/G, G/IR, and R/G) have been found quite suitable for turbidity/suspended sediment assessment in a number of studies.

Another variation of the ratio method is to divide the digital value of each pixel for one band of the later date by the corresponding one of the earlier date. This method is useful especially for multidate studies, which involve monitoring temporal changes.

iii) Density slicing

In order to separate physical classes in a water body, the image is density sliced. Based on the field information, gray level (DN values) groupings are done. This method is especially useful for turbidity mapping.

iv) Principal Component Analysis (PCA)

PCA transforms the axes of the raw multispectral data into a set of axes orthogonal to each other and ordered in terms of variance. The PCs are obtained from the Eigen vectors of the variance-covariance matrix or correlation matrix. The first component accounts for about 90-95 per
cent of variance and can be correlated with turbidity and other water quality parameters.

In the case of monitoring of water bodies, change detection using PCA involves comparison of the PCs of the individual dates. For each set of data, the following operations are performed:

a) Compute the variance-covariance matrix for the two date images.
b) Get the Eigen values and Eigen vectors of the variance-covariance (or correlation matrices).
c) The sum of Eigen values equals the sum of variances. A linear transformation of all the bands is made with constants for multiplication being the Eigen vectors. The output components are principal component images, where each component is decorrelated.
d) The output principal components can be identified as brightness image if all the constants of multiplication are of the same sign or greenness image if the constants of multiplication are of opposite sign for visible bands and IR bands (Landsat MSS and IRS data).
e) The different date PCs of the same type can be superimposed or differenced for locating the changes.

Another way of getting information about changes in a given scene is to use PCA directly on multidate data. In multidate PCA, the first and second components normally give cumulative brightness and cumulative greenness, while the third and fourth components give difference in brightness and greenness respectively.

v) Image Differencing

For temporal monitoring of lakes, reservoir and streams, the gray values of registered multiband images of two date data are subtracted on a pixel-by-pixel basis to obtain difference in each band. By convention, the previous date image (reference image) is subtracted from the later date image of the
same area. The resultant image shows 'positive' and 'negative' digital change values, which can be correlated with water quality parameters.

The operation can be expressed as:

\[ D_b = A + (X_{2b} - X_{1b}) \times B, \]

where, \( D_b \) is difference image in band \( b \), \( X_{1b} \) and \( X_{2b} \) are the digital values of two date images for band \( b \), and \( A \) and \( B \) are the constants for stretching the output values to the display range. The resultant difference image in each band is approximately Gaussian in nature with 'no-change' pixels centred around the mean while the tail contains information about the 'changed' pixels. A critical element of the image differencing method is in deciding where to place the threshold boundaries between 'change' and 'no-change' pixels (Jenson, 1986). A change threshold has to be specified by the user. If a single type of change is to be detected, say from category A to B, the threshold may be specified as the difference in the reflectance/radiance between A and B. The threshold can be also be decided interactively by adjusting it for a training area and then using for the entire image. In some cases, statistical threshold at 1, 2 or 3 S.D. can be applied, especially, if the area contain several categories of changes.

vi) Chromaticity Analysis

For water quality assessment, especially suspended sediments using satellite remote sensing, the chromaticity analysis (Munday et al, 1979) has the soundest physical basis. Also, for monitoring purposes this method is not heavily dependent on ground truth data. This method eliminates atmospheric disturbances affecting all bands in the same proportion. For Landsat MSS (IRS also has similar bands) chromaticity indices \( x \) and \( y \) are calculated as a ratio of Landsat MSS radiances (Lindell, 1983) in the following way:
\[
\begin{align*}
\text{B4} \\
x &= \frac{\text{B4}}{\text{B4} + \text{B5} + \text{B6}} \\
\text{B5} \\
y &= \frac{\text{B5}}{\text{B4} + \text{B5} + \text{B6}} \\
\end{align*}
\]

\(Bi\) = the radiances of the Landsat bands 4-6.

\(x\) and \(y\) describe the colour of the object as seen by the Landsat MSS. Since calculations are based on radiances, radiometrically calibrated data should be used in the studies. Subsequently, gray values are used to calculate the brightness (value), hue (colour) and saturation (colour purity) for each pixel. Afterwards, a correlation is established between these coordinates and water quality parameters.

**STRUCTURAL COMPONENTS OF WETLANDS**

Various types of features (cover types) present in the wetland provide habitat conditions suitable for nesting, resting and roosting. Using satellite data it is possible to delineate structural components of the wetlands such as open water, aquatic vegetation zones, raised areas or islets, water pools, tree vegetation etc. using visual and digital analysis techniques.

**CATCHMENT CHARACTERISTICS OF WETLANDS**

For any wetland management strategy to succeed consideration of its catchment characteristics is of paramount importance. In wetlands ecosystems there is always an exchange of matter and energy between catchment and the wetland. Remote sensing has proved very useful in
characterising the catchments of wetlands in terms of vegetation status, land use, terrain conditions and soils, besides helping in computing sediment load.

LITERATURE SURVEY

Not many studies involving use of satellite remote sensing have been carried out for inventory of wetlands at state or national level. In the following sections a few representative studies of remote sensing technology for wetlands primarily based on space borne remotely sensed data are discussed.

Mapping and Monitoring

Though it is well known that satellite data is very effective in mapping and monitoring of wetlands, nevertheless, on operational level spanning states or country such studies are very few. In India, a study was carried out at Space Applications Centre, Ahmedabad during 1992-93 to map inland water bodies for the states of Andhra Pradesh, Assam, Bihar, Orissa, Uttar Pradesh and West Bengal using post-monsoon and pre-monsoon IRS data on 1:250 000 scale. Various categories included lakes, ox-bow lakes, reservoirs, and tanks. Qualitative turbidity ratings (low, moderate, high) were also assigned to these water bodies.

In a recent study, countrywide wetland inventory of wetlands was carried out using IRS data (Garg et al, 1998). The project was carried out at the behest of the Ministry of Environment and Forests, Govt. of India. 24 wetland categories (10 inland and 14 coastal) were mapped at a scale of 1:250 000/1: 50 000 for the entire country. This is the first scientific inventory of wetlands in the country. Results of the study have been given in Chapter 1 (Table 1.6).

In a study for mapping coastal wetlands along the Indian coast Nayak et al (1992) have used Landsat TM/IRS LISS II data. The study has brought out that at many places mangroves are degraded and destroyed. Coral reefs are
in the degraded condition in the Gulf of Kachchh, and reclamation of backwaters in Kerala is causing a serious ecological problem.

Murthy and Muley (1988) have carried out a study for monitoring waterspread and marsh area for the Chilka Lake (Orissa) using multitemporal satellite data. It was concluded that there is a definite decrease in the water spread of Chilka lake (from 931 sq. km. On November 7, 1972 to 746 sq. km on November 30, 1985) though no uniform yearly pattern was observed. However, the study indicated a positive relationship between rainfall and water spread.

In a recent study Lunetta and Balogh (1999) have found that multi-temporal data is superior for identifying within wetland features such as open water, wetland vegetation (emergent, trees, shrub and agriculture etc.).

**Water Quality**

Spectral variation in the reflectance from water has been made use of in a number of remote sensing based studies for water quality assessment. Water quality studies using remote sensing and field data have been carried out by many workers (Munday and Alfoldi, 1975; Munday et al, 1979; Bukata et al, 1983, Lindell and Rosengren, 1981; Lindell et al, 1985, Arnez et al, 1999) for a particular water body. However, general indices applicable over large areas such as region or a state are yet a far cry.

**Lakes and Reservoirs**

Carlson (1977) has developed a Trophic Index which is basically a linear transformation of Sechhi depth, Chlorophyll 'a' and phosphorous. Verdin (1985) has classified lakes on the basis of Sechhi Depth transparency and Chl-a concentration.
Ortiz Casas and Pena Martinez (1989) have carried out water quality studies in 11 reservoirs in Spain using Landsat TM data. Empirical models (regression equations) were developed between Landsat TM derived DN values and limnological variables (water temperature, chlorophyll, inverse Sechhi transparency). They have observed a high correlation for chlorophyll and inverse of Sechhi transparency by using the data set for all the reservoirs.

In a study of the Dal and Wular lakes in the state of Jammu and Kashmir (Tamilarasan et al., 1989; Palria et al. 1988), the results have been quite revealing. The total water spread area of the Wular lake has reduced to 66.3 sq. km in 1986 from 79 sq. km in 1963 (SOI map) while the total lake area has reduced to 88.4 sq. km during the same period. Temporal satellite data has also been used to study seasonal and long term distribution of turbidity levels. In the same study, the spread of aquatic vegetation due to eutrophication has also been mapped. In the study for Wular lake digital analysis was carried out using band ratios, principal component analysis, chromaticity techniques and classification.

In the investigation of Ramganga reservoir using Landsat MSS data from 1977 to 1987, 4-5 levels of turbidity during the post-monsoon and 3 levels of turbidity during the pre-monsoon season were delineated (Tamilarasan et. al. 1989). Similar studies have also been carried out for Kolleru lake, and Rihand and Matatila reservoirs at Space Applications Centre, Ahmedabad.

Recently, a study was carried out by Cairns et al (1997) using SPOT data for three reservoirs in north Texas in order to determine if SPOT data could be used as a surrogate for water quality measurements. It has been concluded by them that there was a significant correlation between SPOT digital data and both turbidity and chlorophyll a. However, the correlation was too low (0.56) between digital data and chlorophyll a values and concluded that the
techniques still need to be refined sufficiently for using digital data as a practical tool for water quality monitoring.

**Rivers/Streams**

Concurrent with urbanisation, industrialisation and intensive use of fertilisers/pesticides in the catchment areas of rivers, the pollution load in rivers, especially around the urban conglomerates has increased tremendously. Among the major rivers in India, the waters of the Ganga (UP, Bihar, W. Bengal), the Yamuna (Haryana, UP, Delhi), the Godavari (Andhra Pradesh), the Gomti (Uttar Pradesh), the Chambal (Rajasthan), the Hindon (UP), the Kshipra (Madhya Pradesh), the Krishna (Andhra Pradesh), the Brahmani (Orissa), the Damodar (Bihar), the Tapi (Gujarat) and the Narmada (Gujarat) are highly polluted and require pollution control measures.

Studies have shown that quite often industry-induced water pollution can be detected using remotely sensed data. In Kudremukh Iron Ore Mining area (Western Ghats, Karnataka), pollution of the Bhadra river induced by run-off and tailing spill over could be detected using image differencing technique (Garg et al., 1988). Statistically normalised images of 1976 and 1985 were differenced digitally and a thresholding at 1 S.D. level has brought out the above change. In visual analysis, this could not be detected. In Talcher (Orissa), activities related to mining, power generation, and fertiliser production have significantly polluted the water resources. Analysis of satellite data was done to study the river pollution due to the discharge of effluents into the Brahmani river carried through the Nandira Jhor (Garg et al., 1990). In its upper reaches, this rivulet (Nandira Jhor) receives spill over from the NALCO (National Aluminium Company) captive thermal power plant ash pond that makes it whitish. After it receives the effluents from FCI (Fertilizer Corporation of India) which are black in colour, the river practically becomes biologically dead. The effluents/water from this stream after joining the Brahmani river are distinctly seen as a separate channel of water due to
its blackish colour up to 30 km downstream on IRS LISS II FCC of October 1988. Field data has indicated that water upstream of Nandira Jhor has low TDS, turbidity (60 NTU), nitrates (0.007 mg/l) and high DO (7.97 mg/l) and no phosphates indicating a state of no pollution. The upstream waters of the Brahmani river have comparatively higher turbidity (18.4 NTU) and TDS (4.36 mg/l) which may be probably due to discharge of effluents from Raurkela Steel Plant. Water samples from Kendupalli where FCI effluents join Nandira Jhor and Girangalli Bridge where TTPS (Talcher Thermal Power Plant) and FCI effluents are already mixed were taken and analysed. The water appears black on the imagery and has high concentration of phosphates (0.269-0.564 mg/l), nitrates (0.508-0.536 mg/l), TDS (584-920 mg/l) and turbidity (112-179 NTU) with very low DO (2.28 mg/l). Also, water is highly alkaline (pH 10.0). An analysis of 1975 and 1985 satellite data has revealed that earlier the Brahmani river was not highly polluted.

In the study for the Hasdo River near Korba (Madhya Pradesh), three distinct turbidity levels could be delineated using IRS LISS II data of 1988. The high turbidity zone is seen after the Ahiran river meets the Hasdo and extends upto 23 km downstream. The main source of suspended particles is the leakage and overflow from a nearby ash pond into the Ahiran river. Moderate turbidity was observed between Darri and Barampur (9 km), while reservoir and upstream water showed low turbidity (Garg et al, 1990).

Remote sensing also helps in delineation of aquatic weeds in rivers. In a study carried out at SAC for Yamuna Action Plan funded by the Ministry of Environment and Forests, aquatic vegetation (water hyacinth, Ipomoea etc.) was delineated using IRS LISS II/SPOT MLA data of pre-monsoon season.