Chapter 3

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3.1 GENERAL

Space technology in the form of remote sensing satellite imagery and GIS provides a convenient, accurate, cost effective and reliable method of estimating and/or monitoring landcover, vigorousness of vegetation, natural resources distribution, and changes of land use over local, regional and global scales (Wei and Akiyama 2001, Zhang, et al., 2004), delineating areas of riverine and shoreline erosion and buildup, and paths taken by the eroded sediments. Repetitive coverage of susceptible areas facilitates effective monitoring of such erosion problems and planning of suitable control measures. Along with shorelines, erosion and deposition take place by wave action. Where the shoreline has some relief, erosion is dominant; along shoreline of low relief, the characteristic landforms are depositional. These landform of deposition are easily recognised on remotely sensed satellite imagery. Remote sensing data can be used as a tool to detect, monitor and evaluate changes in ecosystems to develop management strategies for ecosystem resources. The broad area coverage and low cost of satellite imagery makes it a cost-effective tool for detecting and delineating major forest changes (Leckie 1990, Holden and Ledrew 1999, Thanikachalam and Ramachandran 2003).

Remote sensing data can be used to span temporal and spatial scales ranging from local systems to aggregated global systems (Jha and Unni 1994). Remote sensing images of land, oceans, seas and inland waters always suffer from atmospheric effects disturbing the direct relation between remotely observed spectral radiance and object spectral reflectance (spectral signature). The molecules and aerosol particles in the atmosphere cause selective extinction of light, i.e., scattering and absorption, depending on the wavelength. Elimination of the influence of the atmosphere is usually called atmospheric correction. It should be realised, however, that the atmospheric effects may be quite large and their removal not a trivial matter. A large number of atmospheric correction methods for optical remote sensing data has been proposed by various workers (Van Stokkom and others, 1993).
3.2 LANDUSE/ LANDCOVER CHANGE STUDIES

Land is the most important natural resource which embodies soil, water and associated flora and fauna involving the total ecosystem. Of late, the growing population and human activities are increasing the pressure on the limited land and soil resources for food, energy and several other needs. Comprehensive information on the spatial distribution of landuse/landcover categories and the pattern of their change is a prerequisite for planning, utilisation and management of the land resources of the country. Landuse/landcover inventories are assuming increasing importance in various resource sectors like agricultural planning, settlement and cadastral surveys, environmental studies and operational planning based on agro-climatic zones. Information on landuse/landcover permits a better understanding of the land utilisation aspects on cropping patterns, fallow lands, forest cover, grazing lands, wastelands and surface water bodies, which is vital for developmental planning. The information requirements for landuse planning comprise reliable, up-to-date and comprehensive data on physical, ecological and socio-economic resources. It is well established that remote sensing has the potential to make the most significant contributions in the area of landuse data collection and more so in the agricultural landuse (Nunnally, 1974). Natural as well as anthropogenic activities were found to be potential reason for the changes in landuse/landcover.

Remote Sensing, in association with other conventional techniques, not only provides a minute coverage of the inaccessible coastal terrain but also helps in collecting information about the subsurface characteristics and offshore features in an efficient and cost-effective way (Nair et al., 1993; Mukherjee and Das, 1999; Das and Mukherjee, 2002). Recording landcover changes over time is perhaps one of the most important applications of remote sensing data (Christenson et al., 1988; Ghosh, et. al., 1996). The advantages of digital satellite image acquisition and analysis techniques for change detection as summarised by Jenson (1986) are: (i) has a systematic period between overflights, (ii) records imagery of the same geographic area at the same time of day to minimise diurnal Sun angle effects, (iii) maintains the same scale and
look-angle geometry. (iv) reduces relief displacement as much as possible and (v) records reflected radiant flux in consistent and useful spectral regions.

IRS-1C LISS-III data of Goa coast was analysed to study various coastal features. Many features such as mudflat, beach, fringe mangroves, creeks, dunes and dune vegetation were clearly delineated. It was observed that mangrove patches which are about 20-40m wide and 100-150m long and bordering creek areas are clearly distinguishable. These areas could not be detected in earlier studies. The identification of two types of mudflats, delineation of smaller creeks, distinction between beach and dunes as well as density-wise classification of dune vegetation are now possible using LISS-III data. IRS-1C PAN data of Tuticorin area, Tamil Nadu was merged with IRS-1B LISS-II data, thus using better spatial resolution of PAN data and multi-spectral capability of LISS-II data (infrared, red and green bands) for discrimination of various coastal features. Dense mangroves were mapped in deltaic regions of East coast, fringing the coast in Andaman and Nicobar islands, estuarine regions of Maharashtra and Goa, Gulf of Kachchh, deltaic regions of Kori creek on Gujarat coast, and Pichavaram and Vedaranyam mangrove forest in Tamil Nadu coast (Nayak, 1994, Thanikachalam and Ramachandran, 2003). Monitoring of landuse/landcover changes in coastal areas using Oceansat-1 data. (specially using OCM) have been done. (SAC, 2004).

Geographic Information System (GIS) is found to be effective in preparing, maintaining and carrying out futuristic analysis on landuse planning and management (Burrough, 1986). Recording land cover changes over time is perhaps one of the most important applications of remote sensing data. (Christenson et al., 1988). Integration of remote sensing data and GIS can serve as a useful guide for the selection of classification training areas and to update data bases for the assessment of spatial and temporally dynamic phenomena. The use of GIS thematic overlays as an aid in the interpretation of remotely sensed data is not widely utilized, although its application has great potential. (Sharma and Anjaneyulu, 1993). An ecological study
of the Mahakam Delta mangrove in Indonesia has been carried out using SPOT imagery (Dutrieux et al., 1990)

3.2.1 Interpretation of Remotely Sensed Data for Landuse/ Landcover

A remote sensor records response which is based on many characteristics of the land surface, including natural and artificial cover. An interpreter uses tone, texture, pattern, shape, size, shadow, site, association and other interpretation elements to derive information about landuse activities from what is basically information about landcover. Anderson and others (1976) have developed a multi-level landuse/ landcover classification system for USA. This classification system is commonly referred to as USGS or Anderson classification system. In this classification scheme, four levels of landuse/ landcover classes classification are suggested. Level-I information can be used at inter-state and statewide levels of planning. Level-II, at statewide to regional scale of planning. Level-III, at regional to local scales of planning, whereas Level-IV information can be used at local or micro-level planning. This multi-level classification system has been used for a detailed landuse and landcover analysis of a part of Konkan coast, San Francisco estuary and Bharatpur, areas using LANDSAT, IRS-1B LISS II and IRS-1C LISS III images (Rao et al., 1991; Dhinwa et al., 1992; McCreary, 1992; Pathan, 1992; Aspinall, 1993). NASA has reported the change in landuse pattern in coastal Kutch area, India, as a precursor of 2001 earthquake (Dimitar, 2001).

3.2.2 Criteria for Landuse/ Landcover Classification

In order to develop a landuse/ landcover classification system for the landuse conditions prevalent in India, it is essential to consider certain criteria and limitations of satellite data and that of the study areas. This is particularly relevant, because a classification system using satellite data should provide a framework to satisfy the needs of a majority of users. For this, certain guidelines and criteria for evaluation have been established. They are:
1. The landuse/landcover classification system involved should be applicable over large areas.

2. The classification system should be suitable for using satellite data obtained at different periods of the year.

3. Assemblage of landuse/landcover categories must be possible.

4. The minimum interpretation accuracy and reliability in the identification of landuse/landcover categories from satellite data should be at least 85 to 95 per cent.

5. Due to the small scale of satellite imagery certain landuse/landcover categories may be generalised. For example, different agricultural crops can be put together under the main category of agriculture.

6. Choice of data should be planned on the basis of the dominant use the map is intended to serve and the levels of details needed. For most purposes, imagery obtained in Kharif and Rabi seasons would be ideal for landuse mapping.

7. To decide on an appropriate classification, or the category level within a classification, an arbitrary decision must be made. One must decide on imagery scale or on the scale of representation of data. Data based on scales of 1:1 million, 1:250,000 and 1:50,000 should serve the three levels, namely, Level-I, Level-II and Level-III classification, respectively.

3.2.3 A Comprehensive Landuse/ Landcover Classification System Developed by NRSA

The array of information available on landuse/landcover needs to be grouped under a suitable classification system. The classification system should not only be flexible in its scope, definition and nomenclature of its categories, but also be capable of incorporating latest information obtained from different sensor data and other
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sources. Such a landuse classification system, based on the understanding that the remote sensing techniques can be used effectively to complement traditional surveys for an accurate inventory of the landuse and landcover in the country, was proposed by Gautam and Narayan (1982) to suit the Indian conditions. Subsequently, National Land Use/Land Cover Classification System for India has been developed under the National Remote Sensing Agency (NRSA), Department of Space, in consideration of the views of the several user departments including the Planning Commission of India. The system is fairly compatible with those followed by most of the other government department in the country Table 3.1.

Table 3.1 Landuse/ Landcover classification system developed by NRSA (1989)

<table>
<thead>
<tr>
<th>Level-I</th>
<th>Level-II</th>
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<tbody>
<tr>
<td>1. Built-up land</td>
<td>1.1 Built-up land</td>
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<tr>
<td>2. Agricultural land</td>
<td>2.1 Crop Land</td>
</tr>
<tr>
<td></td>
<td>Kharif</td>
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<tr>
<td></td>
<td>Rabi</td>
</tr>
<tr>
<td></td>
<td>Kharif+Rabi</td>
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<tr>
<td></td>
<td>2.2 Fallows</td>
</tr>
<tr>
<td></td>
<td>2.3 Plantations</td>
</tr>
<tr>
<td>3. Forest d</td>
<td>3.1 Evergreen/semi-evergreen forest</td>
</tr>
<tr>
<td></td>
<td>3.2 Deciduous forest</td>
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<td></td>
<td>3.3 Degraded or scrub land</td>
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<td></td>
<td>3.4 Forest blank</td>
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<tr>
<td></td>
<td>3.5 Forest plantation</td>
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<tr>
<td></td>
<td>3.6 Mangrove</td>
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<tr>
<td>4. Wastelands</td>
<td>4.1 Salt affected land</td>
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<td></td>
<td>4.2 Waterlogged land</td>
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<td></td>
<td>4.3 Marshy/swampy land</td>
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<tr>
<td></td>
<td>4.4 Gullied/ravinous land</td>
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<tr>
<td></td>
<td>4.5 Land with or without scrub</td>
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<td></td>
<td>4.6 Sandy area (coastal and desert)</td>
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<th></th>
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<th>4.7 Barren rocky/stony waste/sheet rock area</th>
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<tr>
<td>5.</td>
<td>Water bodies</td>
<td>5.1 River/stream</td>
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<td></td>
<td></td>
<td>5.2 Lake/reservoir/tank/canal</td>
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<tr>
<td>6.</td>
<td>Other</td>
<td>6.1 Shifting cultivation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.2 Grassland/grazing land</td>
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<tr>
<td></td>
<td></td>
<td>6.3 Snow covered/Glacial area</td>
</tr>
</tbody>
</table>

a = It includes land under agricultural crops during Kharif, Rabi (both irrigated and unirrigated) and the area under double crop, during both the seasons.

b = It is that land which remains vacant without crop during both the Kharif and the Rabi seasons.

c = It includes all agricultural plantations like tea, coffee, rubber, coconut, arecanut, citrus and other orchards.

d = It includes those areas which occur within the notified forest boundary as shown on the Survey of India topographic maps on 1:250,000 scale. Those occurring outside the notified areas are also included under forest class, but the area estimates of the two will be shown separately.

e = It includes plantations within the notified forest boundary e.g., cashew, casuarina, eucalyptus, etc. Those occurring outside the notified areas will be classified under category 2.3. The area estimates of the two will be shown separately.

f = It includes inland fresh water lakes, salt lakes, coastal lakes and lagoons.

Note: 1. Mining and industrial wastes, salt-pans, reclaimed lands, classes relevant to a particular district will be mapped separately, wherever feasible. These will be classified under Others.

2. Tidal mudflats which are visible during low tides along the coastal areas will also be mapped separately if these are identified on satellite imagery. These will be classified under Others.

3.3 VEGETATION/FOREST STUDIES

Satellite sensor data have emerged as an important tool for inventory and monitoring of vegetation resources. The real time information provided by the multi-date satellite sensor data improves the prospects for monitoring, assessment and management of vegetation covers efficiently and effectively. A considerable amount of work has already been carried out both by photo interpretation as well as by quantitative analysis. Forest decline has been defined as "A perceived reduction in the 'health' of a forest ecosystem which may be characterized by unexpected changes in growth, reproduction and death of trees". Many workers believe that forest decline is the result of complex interactions between the environment and natural ecosystems. These complex environmental factors (stress) can include variability in weather, nutrient availability (too much or too little, e.g. nitrogen), outbreaks of herbivorous insects and pathogens, acid deposition and acid cloud or fog water, atmospheric
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deposition of toxic metals, elevated atmospheric concentrations of ozone and SO$_2$, etc (Likens, 1989; Smith, 1995).

A variety of spectral measures that relate to chlorophyll content or plant stress have been developed. As leaves become more chlorotic, reflectance increases and the reflectance peak normally centered at about 0.55μm, broadens towards the red as absorption of incident light by chlorophyll decreases. The more commonly used spectral measures of vegetation, which rely on the region of the red edge, have been used to estimate vegetation biomass, productivity, leaf area index, photosynthetic activity or chlorophyll content. The most common of these measures are the various ‘vegetation indices’. The simplest is the vegetation index (VI), sometimes called the ratio vegetation index (RVI), which is a ratio of the infrared to red radiation (Jordan 1969, Tucker 1979). Several variations have emerged over the years, notably, the perpendicular vegetation index (PVI) proposed by Richardson and Wiegand (1977), the greenness index of Kauth and Thomas (1976), and the soil adjusted vegetation index (SAVI) of Huete (1988), all of which were introduced to better account for background reflectance from soil. Another measure, the normalised difference vegetation index (NDVI), was proposed by Rouse et al. (1974) to minimise the sensitivity to noise. Although superficially different, there appears to be little functional difference among most of these indices (Perry and Lautenschlager, 1984).

Two of the most widely used red edge measures are the vegetation index (VI), (VI = IR/ Red) and the Normalized Difference Vegetation Index (NDVI).

\[ \text{NDVI} = \frac{(\text{IR} - \text{Red})}{(\text{IR} + \text{Red})}. \]

A ratio of the red band to the IR band enhances the sensitivity to stress relative to ratios based on visible bands only, by capitalizing on the opposing response in red and IR bands. Spectral ratios tend to eliminate differences that are due only to illumination variations and provide a more stable measure of the vegetation type as well as a more reliable indicator of stress. VI and NDVI have been applied to
broad band measurements as well as narrow band measurements. NDVI is highly correlated with many vegetation parameters such as crown closure, leaf vigour, canopy biomass and leaf area index and is the most robust of the vegetation indices developed (Lyon et al., 1998; Krishnaswamy et al., 2004).

3.3.1 Vegetation Composition Change Studies

Remote sensing is able to detect changes in vegetation spectral reflectance. The spectral reflectance is the radiance, or energy in the electromagnetic spectrum (EMS), expressed as a percentage of the incident radiation through a range of wavelengths. The 400-2500 nm range includes most of the incident radiation of the solar spectrum, and is therefore most widely used for remote sensing of vegetation (Carter 1991, Carter 1993). In order to measure change in vegetation over time, one must be able to identify the relevant groups or species to be observed. Visual interpretation of the multi-temporal images can reflect changes in the vegetation to an analyst. Stereograms, photographs taken along the same flight strip that overlap by at least 50%, allow scenes to be viewed in three dimensions with the aid of stereoscope. This device can aid the interpreter in determining landscape changes (Lillesand and Kiefer, 1994). This technique works well with data taken by conventional colour and colour-IR photography. The interpreter can use features in the photograph such as shape, size, tone, shadow, patterns, texture and association to discriminate different types of vegetation.

Another method involves classifying the data with aid of computer. Images taken digitally, such as with the Digital Multi Spectral Video (DMSV), record the individual pixels, that comprise an image as data of brightness values (digital numbers) ranging from 0-255. 256 shades are used because each pixel per band is comprised of 8 bits. Since each bit can carry an electronic value of 0 to 1, each pixel per band, can be displayed by one of 28, or 256 shades. Each pixel of a colour IR image can be associated with wavelengths in the blue, green, red and IR frequencies. The DMSV is capable of collecting four data (four separate wavelengths in the EMS)
for each pixel. When displayed for use by the analyst, three bands are selected and assigned red, green, and blue colours, producing a ‘false-colour’ image. Each pixel is thus comprised of 24 bits, with 8 bits assigned to each colour. Satellite instruments can record information from more EMS wavelengths, with each wavelength range being referred to as a ‘band’. These can be entered as data into a computer for classification, or grouping, into several classes depending on the user-defined goals. Each pixel within the image is assigned a particular class. The computer analyzes the different bands and groups the most closely associated pixels together with each other.

Groundtruthing is essential in this stage. The computer can separate pixels into different classes, but only interpreter can give those classes meaning. Theoretically, every pixel’s precise digital numbers (DNs.) will be different. The computer clumps similar pixels together, with ‘similar’ being decided by the mathematical formula used, such as the ‘minimum-distance-to-means-classifier’ or ‘parallelepiped classifier’. The producer must determine, using groundtruthed data, which groups represent different species, or which groups are artifacts of statistical analysis. The classification can be supervised, which involves the use of training data to separate pixel into previously determined categories, or unsupervised, which simply groups pixels into different spectral classes (Lillesand and Kiefer, 1994).

3.3.2 Vegetation and Pollution Studies

While detecting vegetation one has to take several factors in consideration, such as: a) planning a proper field survey and considering whether to use satellite or aerial imagery, b) resolution of sensor, c) film used in aerial photography, and sensors of satellite and Digital Multi Spectral Video (DMSV).

A Stress has been defined as “any environmental factor capable of inducing a potentially injuries strain on a plant” whereas, a strain is “any physical or chemical
change in a plant produced by stress”. A stress must have a detectable effect on this part of the spectrum for visible and near infrared, and short-wave infrared remote sensing to be effective. When a stress causes a detectable change in vegetative reflectance, the site should be examined through ground work. While spectral reflectance depends on such factors as the species, site, maturity, nutrient status, and leaf orientation of vegetation, one of the first visual symptoms of physiological injury is vegetation yellowing or chlorosis (Murtha, 1982).

Vegetation stress can manifest itself as many strains, and can be morphological, affecting vegetation shape or form, or physiological, affecting vegetation function. The physiological effects often appear before the morphological. For example, a plant that restricts water flow through its stem will show signs of wilting after the restriction occurs. Some changes, such as seasonal changes, are normal. The detection of stress relies on being able to determine and detect deviations from normal function (Murtha, 1982). Detecting pollution in stressed ecosystem is usually an ‘after-the-fact’ event. We can generally observe the effects of pollution on an ecosystem, not the pollution itself. Pollutants must be measured as a function of stress on vegetation, which we can detect. For example, we can not detect excess nutrients entering water ways as runoff using remote sensing. However, we can detect the increased spectral reflectance at 550 nm (green band) caused by algal blooms utilizing the nutrients as eutrophication sets, in or the increased spectral reflectance at 650 nm (red band) caused by red tide dinoflagellates.

Colour infra-red photography has been used to detect moderate levels of stress in forest and shrub canopies over limited areas. MSS data of Landsat 4 and 5 are most useful in detecting major patterns of changes in phytomass, using the normalized difference of infra-red and red band as an index. Western (1988), have used aircraft-derived Thematic Mapper Simulator (TMS) and Landsat TM data to examine spectral changes arising from low to moderate foliar injury symptoms characteristic of ozone damage in two areas of southern California. In the Los Angeles basin of coastal
southern California, they observed changes in coastal sage scrub along the 52 km axis of the Santa Monica Mountains.

An experiment performed by Milton et al. (1989), on soyabean plant (*Glycine max*) demonstrated the effects of different pollutants on morphological and spectral reflectance. In addition to reflectance changes, the plants displayed morphological changes. Plants exposed to arsenic had “lower overall biomass, stunted and discoloured roots. and smaller leaves oriented more vertically than leaves of control plants”. Plants exposed to selenium also experienced morphological changes, but lesser than arsenic exposed. While arsenic and selenium are not directly observable from an aerial or satellite platform, it is possible to observe their effects on vegetation by monitoring for detectable signs of stress. Other stress agents may have effects on spectral reflectance similar to those of arsenic and selenium. Groundtruthing is important not only for verifying the measurements acquired through remote sensing, but also to determine the cause for observed deviations from the normal (i.e. the “average” or exposed spectral signature of a given ecosystem).

Vogelman and Rock (1986), have used Simulated Thematic Mapper (TMS) data from the NS-001 sensor aboard aircraft to detect differences in damage to red spruce forest in Camel’s Hump area of the Green Mountains of Vermont, an area subjected to acid deposition and ozone. They found that the $1.65/1.23 \mu m$ (NS-001 TMS bands 6/5) and $1.65/0.83 \mu m$ (NS-001 TMS bands 6/4, or Landsat TM bands 5/4) ratios were useful in discriminating high from low damage sites.

Remote sensing and GIS can also be used for fire risk prediction for particular forest regions and for whole country, fire monitoring, inventory of fire damage to forests, assessment of losses and monitoring of forest regeneration and/or afforestations (Jaiswal, et al, 2002). Analysis of different TM band combinations led to the conclusion that particular bands provide data enabling forest inventory.
management and damage assessment. TM-3 is best for delineating coniferous forests: mixed, deciduous stands and grasslands are best distinguished using TM-4 data, while TM-5 and TM-7 bands can be used for delineating clear-cuts with no vegetation cover and for discriminating mixed for deciduous stands from young spruce stand, grasslands and afforestation areas. The TM-5/TM-4 ratio is best for detecting and classifying damaged spruce (Zawila-Niedwieki, 1996). There are many studies where it is found that due to air pollution forest are getting damaged which are leading, to decline in forest cover. Most of the study on forest decline is conducted by remote sensing satellite and GIS technology (Lambert et al, 1995; Jha and Unni, 1994; Rees and Williams, 1997; Nelleman and Fronger, 1994; Frank, 1991; Kandler and Innes, 1995; Zawila-Niedwieki, 1996; Jaiswal and Mukherjee, 1999; Jaiswal et al, 2003). Most of the air pollution study related to forest damage is done on pine forest (Lomsky and Sramek, 1999; Mazurski, 1990).

There are many studies on thermal power plants and mining areas, where people have done some air pollution studies. They have successfully detected dispersion of plumes from thermal power stations using remote sensing data and GIS techniques (Garg et al, 1989. Meer-Mohar et al, 1993; Singh et al, 1997. Azeem, 2000). The characteristics of Landsat TM and ERS-1 imagery enable quantitative analysis of different open cast mine features, such as, waste, water bodies, landuse change, reclamation process and estimation of vegetation cover of the affected areas (Schmidt and Glaesser, 1998; Rathore and Wright, 1993; Ghosh and Ghosh, 1990; Gautam, 1995; Khanna and Kondawar, 1991).

In many industrial areas people have done environmental impact assessment using remote sensing and GIS techniques. Basically the studies are based on generating different categories of landuse map of the areas, and then these categories were correlated with different causes viz. water pollution, air pollution, and other developmental activities (Jaiswal and Mukherjee, 1999). For most of the study Thematic Mapper and MSS data of LANDSAT have been used (Srivastava et al.
1995). Many workers have identified air pollution plume on imagery. These plumes are generally white in colour on imagery (Majumdar and Sarkar, 1994; Shukla et al, 1995).

Harmful effects of air pollutants on forest ecosystems include direct effects on leaves and indirect effects via soil. Soil acidification causes depletion of cations, decreases base saturation and increases the molar ratio of aluminium to base cations, which has been related to forest damage. In addition to soil acidification, nitrogen depositions disturb the nutrient balance causing reduced winter hardiness and reduced occurrence of mycorrhiza in soil. Drought, insects and damages caused by heavy metals, which often become more soluble at lower pH, are other mechanisms believed to play role in forest damage and decline (Ardo et al, 1997). Acid rain and acid cloud or fog water can significantly alter the structure and/or function, and thus stress, various components of terrestrial ecosystem. Terrestrial ecosystems, however, may be stressed simultaneously by a variety of other air pollutants, such as ozone, toxic metals, hydrocarbons and dry deposited particles. The common source of many of these pollutants is the fossil fuels.

3.4 COASTAL ZONE MONITORING

Coastal zones present a unique environment where water, land and atmospheric components interact. In order to have a better understanding of the coastal processes to adopt suitable coastal zone management practices, the study of the coastal environment in terms of its geology, geomorphology, land use/landcover and the erosional and depositional processes at work on them, is very essential. With the development of remote sensing techniques and the launching of new generation Indian Remote Sensing Satellites (IRS), the task has become much easier. Monitoring of coastal environment were done by using remote sensing satellites IRS LISS-II, Landsat TM data (Nayak and others, 1989).
Many investigators have carried out morphological change studies using temporal satellite data. Pramanik and Jabbar (1990) used temporal satellite data to monitor coastal zone dynamics in Bangladesh. Erosional features of West Bengal coast are being studied by satellite imagery and ground verification. Change monitoring of coastline erosion along the delta region of West Bengal was done by using LANDSAT data (Gupta and Munshi, 1983). Nayak and Sahai (1983) carried out change detection studies in Mahi estuary using LANDSAT data and change detection study of islands in the Hooghly estuary using multi-date satellite imagery was carried out by Kumar et al. (1994). The dynamic landscape of West Bengal coast shows severe land erosion in Ganga delta. Erosion was found extensive in Dalhousie Point, Ganga sagar (Sagar Island), Namkhana, Kakdwip (northwest portion), Duhlat and Bijoyhati of Sundarbans area (Paul and Bandyopadhyay, 1987). Remote sensing change detection is a process for determining and evaluating differences in a variety of surface phenomenon over time. Detecting, describing and understanding changes in physical and biological processes and regulating the Earth’s systems is of considerable interest to ecologists and resource managers.

3.5 REMOTE SENSING OF COASTAL WETLANDS, MARSHES, WATERLOGGED AREAS, MARINE AND ESTUARINE ENVIRONMENTS

Wetlands have been well known by the terms such as marshes, swamps and bogs, for centuries. The most commonly accepted definition of wetland is as follows: “Wetlands are lands transition between terrestrial and aquatic systems where the water-table is usually at or near the surface or the land is covered by shallow water”. Wetlands must have one or more of the following attributes: (1) at least periodically, the land must predominantly support hydrophytes; (2) the substrate must be predominantly undrained hydric soils, and (3) the substrate must be non-soil which is saturated with water or covered by shallow water at some time during the growing season of the year (Dwivedi and Rao, 1999). Wetlands play an important role in bio-geochemical cycling, flood control, water quality maintenance, recharging of aquifers and serve as potential sites for aquaculture and recreation. The wetlands of
Sundarbans and its adjoining areas support a variety of flora and fauna and they are currently being used for fish culture.

In India, coastal wetland mapping and shore-line change detection along the east and west coast of India has been carried out using remotely sensed data (SAC 1991; Mukherjee and Das, 1999). The waterlogged areas/marshes have been mapped for 236 districts under the nationwide wasteland mapping programme (NRSA, 1985). The water logged areas/ marshes and the mangrove ecosystems of Andaman and Nicobar Islands have been mapped using IRS-1A LISS data (Dutt et. al., 1988 and Mukherjee, 1990). Wetlands in the Sundarbans delta and its environs have been mapped using European Remote Sensing Satellite (ERS-1), Synthetic Aperture Radar (SAR) data. Indian Remote Sensing Satellite (IRS-1B), Linear Imaging Self-Scanning (LISS-II) data, collected either concurrently or close to SAR data overpass, were also interpreted/ analysed (Dwivedi and Rao, 1999). IRS-1C LISS-III data of northwest Gulf of Kachchh were analysed to identify various features related to mangrove ecosystem. Use of middle infrared was attempted essentially to distinguish tree and shrub mangroves. The combination of red, infrared and middle infrared bands helped in distinguishing tree mangroves, *Rhizophora* spp. and shrub mangroves, *Avicennia* spp. This distinction was possible because of the different spectral properties of canopies of two types of mangroves produced by a combination of individual vegetative components, effects of plant growth, density and height. This new information is extremely useful for biodiversity studies. This combination also helped in distinguishing between i) sandy area, salt pan and saline area. ii) high tide, inter-tidal and sub-tidal mudflats, and iii) terrestrial vegetation, mangroves and dune vegetation (Nayak, et.al., 1996).

Estuaries, wetlands, and deltas are environmentally sensitive areas that may require periodic monitoring, especially if oilfields or chemical facilities are located nearby. For the purpose of monitoring changes in these areas it is appropriate to use colour or colour infrared satellite imagery or aerial photographs. It should be possible
to monitor blue-green algae growing in ponds by taking advantage of their chlorophyll reflectance peak at 0.7-0.75μ. Algae may be distinguished from suspended sediment by subtracting the reflectance at 0.665μ from the peak reflectance at 0.710μ. The Fraunhofer Line Discriminator (FLD) can detect oil refinery waste, sewage effluents, feedlot effluent, sludge (wet or dry), algal blooms, and phosphate processing effluents by measuring the luminescence of these materials. Fraunhofer lines are absorption bands in the solar spectrum, using sun as a source the FLD measures luminescence in these absorption bands under daylight conditions (Prost. 1994).

Operator's permits for the power plants and refineries often require monitoring of surface temperatures of cooling water discharges. Thermal imagery can be used to monitor these thermal plumes. Thermal imagery has been used since the mid seventies to detect acid mine drainage into fresh water bodies. Aircraft imagery can produce high-resolution imagery at frequent intervals, but costs are relatively high. It has been shown that LANDSAT TM thermal imagery has been sufficient thermal and spatial resolution to map the cooling effluents from power plants such as the Diablo Canyon nuclear facility (Prost, 1994).

3.6 WATER RESOURCE STUDIES

The remote sensing technology and GIS tools have opened new paths in water resource studies. A remote sensing image offers a split-second synoptic view of processes taking place. Water bodies in general are characterized by a high temporal and spatial variability. Roughly knowing this time-scale and spatial variability of the various processes gives insight in the possible use of remote sensing imagery and the desired data-acquisition frequency. For monitoring purposes a sufficient amount of images is required to follow these processes. Satellite imagery, for instance, is adequate to monitor year to year waterplant developments over extensive inland water areas (Van Stokkom et. al., 1993). With airborne measurements, although expensive compared to present-day prices of satellite imagery, a high acquisition
frequency can be achieved, which enables one to monitor small-scale processes with time-scales from minutes to days. Furthermore, synoptic imagery can improve monitoring by contribution to the interpretation of point measurements and to the optimisation of monitoring networks. IRS-1A LISS-II imagery and IRS-1B LISS-II satellite data have been used to study the groundwater potential in the coastal zone of Srikakulam district (A. P.) and Ganjam district in south Orissa, respectively (Murthy, et. al., 2003; Tripathy, et. al., 1997). GIS and remote sensing applications have been used by numerous scientists in mapping of groundwater potential zones (Venkatachalam et al., 1991; Ghose, 1993; Pradeep, 1998; Sankar, 2002; Khan and Moharana, 2002). Sharma and Anjaneyulu (1993) has applied remote sensing and GIS for water resource management.

Passive optical remote sensing has proved to be a valuable tool in providing synoptic information on a number of water parameters. This information can be used directly for water management decisions but is more valuable in building up knowledge on the functioning of the aquatic ecosystem. A number of quantitative applications of optical remote sensing have been developed, providing, for example, image-products of concentrations of suspended sediments, algae, yellow substances and Secchi disk transparencies. With regard to present satellite imagery quantitative water applications are difficult to develop due to the high temporal variability of the water body itself, the relatively high mutual correlation of water parameters, the influence of the water surface, the generally low spectral reflectances, the low radiometric sensitivity of satellite instruments, the poor discrimination of water parameters by present remote sensing instruments, the relatively strong contribution of the atmosphere to the detector signal and the poor availability of adequate data-processing systems. In addition, spectral signatures of various water bodies, each containing a certain composition of constituents, are generally similar. This restrains the possibilities of distinguishing those constituents and estimating their concentrations. High resolution imaging spectrometry could be valuable in coping with quite a number of these items (Van Stokkom, et.al., 1993).
In order to ascertain adequate and accurate functional relationships one should pay considerable attention to the acquisition of adequate water samples with regards to the user-required information. During the actual execution of the water sampling accurate recording of time and geo-referenced positioning of the samples are needed. Especially, in cases of larger areas and of waters with a high temporal variability (e.g., due to tidal influences as shown by Garcia and Robinson, 1991), a problem to be coped with is the difference in time between the remote sensing data acquisition and the sampling. Duggin and Robinove (1990) state in this respect: ‘Failure to ensure this synchronization in image and in ground data acquisition might result in the comparison of two unrelated data sets.’ This problem can be partly solved by sampling by helicopter, which makes it possible to sample a large area in a short time period. Well-defined and (inter) calibrated procedures for sampling, sample conservation and laboratory analysis are required and must be implemented. When high spectral resolution remote sensing data are operationally (commercially) available, modeling the underwater light field and determining the optical properties may be powerful tools for the quantitative use in water applications (Dekker, et. al., 1991).

3.6.1 Water Pollution Studies

Pollution of water is the most important problem, since water plays a vital role in the biological system. It is well known that less than 1% of the total world water supply is fluid fresh water, which is important to the mankind. Man utilises water bodies as source of drinking water, food, transportation and recreation. Often, the same water becomes sinks for man’s wastes as well. 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 estuaries. Also significant sediment loads by natural processes are brought into these water bodies. These results 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 (Tamilarasan et al, 1989).

Pollutants mostly derive from industrial, commercial or agricultural activity, and the need to dispose of human waste, and may also be released from marine sediments. They enter the marine environment by a number of routes: from river discharges and direct run-off from adjacent land, outfall from pipes, atmospheric fall out, deliberate dumping from ships, or accidental spillage often resulting from collisions. High concentrations of pollutants tend to be rapidly dispersed and diluted and thus may build up as lower concentrations over much wider areas. Remote sensing of both levels of concentration have been attempted. Most remote sensing work has concentrated on pollution from point sources as it is much less problematic and it often contrasts sharply with the surrounding water. Clark (1993) provided an extensive review of application of remote sensing on the pollution of marine environment.

Wave characteristics and surface wind speeds can be measured by means of remote sensing in the microwave portion of the electromagnetic spectrum. There are a number of different sensor types that use microwaves for different purposes. Radar altimeters are able to measure the height of the sea surface and can also measure wave heights (Carter et al., 1990). Scatterometers can measure surface wind speeds. Synthetic Aperture Radars (SAR) produce images that are independent of solar illumination and so can image equally as well at night or daytime. Because of their long wavelengths they are unaffected by cloud cover and so are the only type of remote sensing that can guarantee imaging a key area irrespective of day or night or weather conditions. SAR imagery can provide valuable information on wave direction and wavelength. A useful review of microwave remote sensing in relation to the marine environment is contained in Allan (1992).
3.6.2 Sources of Water Pollutants

There are various sources of pollutants (natural as well as anthropogenic), discharge pollutants in the environment that affect the water quality, are listed below (Meyer and Welch, 1975).

- Plant nutrients, which promote growth of aquatic plant life such as algae and water-weeds.
- Infectious biological/non-biological agents contributed by domestic sewage and certain kinds of industrial waste, which may transmit disease.
- Organic wastes contributed by municipal sewage and industrial waste of plant and animal origin, which remove oxygen from water through decomposition.
- Synthetic organic chemicals such as detergents and pesticides resulting from new chemical technology are toxic to aquatic life such as fishes, algae and also to human beings.
- Inorganic chemicals 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.
- Sediments that fill streams, channels, reservoirs and harbours, cause erosion of hydroelectric power and pumping equipment, affect the fish and shellfish population by blanketing fish nets and increases the cost of water treatment.
- Temperature increases which results from the use of water for cooling purposes by thermal power plants, 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.
- Radioactive pollution resulting from the mining and processing of radioactive ores and from the use of refined radioactive matters.
3.6.3 Remote Sensing of Water Pollutants

Surface water is easy to monitor because of the uniform background that the clean water present on imagery. All water pollutants cannot be sensed and measured remotely. Features that can be monitored include suspended particulates, change in water clarity, algal blooms, effluents and thermal (hot or cold) discharges and mixing zones. Remote sensing can sense only those pollutants that affect the colour and intensity of reflected light of a water body. For example, many dissolved chemicals have no specific spectral signature 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 sensing detection and measurement. So, it is essential to measure the colour and the brightness of water to detect water pollutants. The phenomena that impart specific colour and brightness to an image of a water body can be classified into six broad categories.

- Source characteristics,
- Atmospheric effects,
- Surface reflectance,
- Volume reflectance,
- Bottom reflections, and
- Sensor characteristics.

Most remote sensing techniques examines only the surface micro-layer. It is not possible to determine the depth to the water table or to locate water table contamination using conventional imaging remote sensing technology. Similarly, there are no conventional imaging techniques that will locate or track hydrocarbon accumulations on the groundwater surface. Radar flown from aircraft or satellites can penetrate up to 2 m under ideal conditions, whereas ground-penetrating radar, a non-imaging system, can detect the water table at maximum depth of about 50 m (Prost. 1994).
3.6.4 Physical Principles and Interaction of Electromagnetic Radiation (EMR)

Water parameters, which affect the energy levels recorded by the sensors, are colour and turbidity. An increase in water colour 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. Detail of interaction mechanism of EMR with water body is discussed below.

Remotely sensed data from satellites is based on interaction of EMR from Sun with various terrain features, which interact in different fashions with the incident EMR and hence give rise to contrast in the remotely sensed data. EMR on any terrain feature will undergo absorption (A), reflection (R) and transmission (T), which will vary from one terrain feature to the other. Remote sensing sensors operating in visible region of EMR record the reflected component from the terrain feature and convert the reflected radiation to analog electrical signals. These signals are sampled on board the platform and are converted to digital numbers (DNs), which are transmitted to receiving station. The DNs have linear relationship with the reflected radiation (Jonna et al. 1989).

The reflected radiation reaching the sensor on board a satellite consists of various components. For detailed study of water quality using remotely sensed data, the understanding of interaction of EMR with water bodies and the intervening atmosphere column is required. The EMR incident on a water surface is partly specularly reflected, partly absorbed and partly scattered. The EMR that is specularly reflected and absorbed by water body is not available for remote sensing purposes in visible region of EMR. The primary indicative signal that is useful for water quality studies is the volume reflectance and backscattered energy caused by the impurities in
water. However, in addition to this signal, radiation reflected by the water surface and bottom (depending upon the depth of water) reach the sensor (Jonna et al. 1989).  

If the solar energy that reaches a water surface is represented by $I_o$, the interaction expressed 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 at $30^0$-60$^0$ sun-elevation angles. However, corrections for specular reflection should be made, while measuring spectral signature of water bodies. If specular reflection is imaged by a camera or scanner it is called sunlight. 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 a multi-spectral 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 $30^0$. The way light is absorbed, scattered and reflected (spectral characteristics) is selective and depends on the materials in the water. In shallow and turbid water, it is not possible to separate signals from bottom and from the suspended sediments. The light that penetrates into
the water and reaches the surface again after scattering and reflection carries
information about the water quality. Blue light scatters more than the red light.

3.6.5 Remote Sensing 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, e.g. a camera is a
passive sensor but when fitted with a flashlight it becomes an active sensor. The
instrumentation requirements for remote sensing of pollutants as described in NASA
SP-285, are given in the Table 3.2.

A photographic system uses a camera with filters to record light energy of different
wavelengths. Photographs can be black-and-white, colour or colour infrared (CIR). A
multi-band aerial photography records subtle differences in spectral reflectance and
thus provides a powerful tool to detect sources of pollution and to monitor pollutant
dispersion. Pollutant 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 photographs are comparatively less affected by atmospheric
haze.

Table 3.2 Measurement Requirements for Remote Sensing of Pollution

<table>
<thead>
<tr>
<th></th>
<th>Spatial Resolution</th>
<th>Spectral Resolution</th>
<th>Spectral Range</th>
<th>Temporal Resolution</th>
<th>Solar Elevation</th>
<th>Look range (From Nadir)</th>
<th>Area Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>10-30m</td>
<td>Broad-band</td>
<td>UV, Visible Microwave</td>
<td>2-4 hrs.</td>
<td>Only important with glitter</td>
<td>Only important with glitter</td>
<td>200-200km (20-20km)</td>
</tr>
<tr>
<td>(300)</td>
<td></td>
<td></td>
<td></td>
<td>(1 day)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended Sediment</td>
<td>20m</td>
<td>0.15μm</td>
<td>350-800nm</td>
<td>2 hrs.</td>
<td>45°</td>
<td>0 to +15°</td>
<td>350-100km (10-10km)</td>
</tr>
<tr>
<td>(500m)</td>
<td>(0.15μm)</td>
<td>(400-700nm)</td>
<td>(1 day)</td>
<td>(30°-60°)</td>
<td>(-5° to +30°)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Chem. &amp; Toxic Waste</th>
<th>10m (200m)</th>
<th>0.015μm (0.015μm)</th>
<th>350-700nm (400-700nm)</th>
<th>5 hrs. (10 day)</th>
<th>45° (30°-60°)</th>
<th>0 to +15° (-5° to +30°)</th>
<th>35-35 km (10-10 km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Waste</td>
<td>10m (200m)</td>
<td>0.015μm (0.015μm)</td>
<td>350-800nm (400-700nm)</td>
<td>5 hrs. (10 day)</td>
<td>45° (30°-60°)</td>
<td>0 to +15° (-5° to +30°)</td>
<td>35-35 km (10-10 km)</td>
</tr>
<tr>
<td>Thermal Effluents</td>
<td>30m (500m)</td>
<td>±0.2°C</td>
<td>10-12μm (10-14μm)</td>
<td>2 hrs. (10 day)</td>
<td>N/A</td>
<td>To be determined</td>
<td>35-35 km (10-10 km)</td>
</tr>
<tr>
<td>Radioactive Wastes</td>
<td>30m (500m)</td>
<td>N/A</td>
<td>Gamma (Gamma)</td>
<td>5 hrs. (15 day)</td>
<td>N/A</td>
<td>0°</td>
<td>35-35 km (10-10 km)</td>
</tr>
<tr>
<td>Nutrient Wastes</td>
<td>100m (2km)</td>
<td>0.005μm (0.015μm)</td>
<td>400-700nm (400-700nm)</td>
<td>2 days. (14 days)</td>
<td>45° (30°-60°)</td>
<td>0 to +15° (-5° to +30°)</td>
<td>350-350 km (10-10 km)</td>
</tr>
<tr>
<td>Introduction of Species</td>
<td>To be Determined</td>
<td>0.1μm (0.1μm)</td>
<td>Visible (Visible)</td>
<td>3 months (Years)</td>
<td>N/A</td>
<td>N/A</td>
<td>350-350 km (10-10 km)</td>
</tr>
<tr>
<td>Red tide</td>
<td>30m (2km)</td>
<td>0.015μm (0.015μm)</td>
<td>400-700nm (400-700nm)</td>
<td>5 hrs. (2 days)</td>
<td>45° (30°-60°)</td>
<td>0 to +15° (-5° to +30°)</td>
<td>350-350 km (20-100 km)</td>
</tr>
<tr>
<td>Human &amp; Cultural Effects</td>
<td>10m (100m)</td>
<td>Variable*</td>
<td>UV, Visible Microwave</td>
<td>1 year (5 years)</td>
<td>N/A</td>
<td>N/A</td>
<td>350-350 km (35-35 km)</td>
</tr>
</tbody>
</table>

*N/A - not applicable. ** An optimum value and an (acceptable value) are given for each entry.

(Source: NASA SP-285, 1971)

Regional survey 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.

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

Radiometers, spectrometers and scatterometers have been used for water quality studies. The in-situ instruments using Secchi disc, Nephelometer (for turbidity measurements), ground truth radiometers (for measurements of spectral signature of water bodies), infrared thermometers (for temperature 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 in the table 3.3 (Meyer and Welch, 1975).

Table 3.3 Useful Spectral Ranges for the Study of Water Quality

<table>
<thead>
<tr>
<th>Water quality parameter</th>
<th>Useful spectral range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended sediment</td>
<td>V, IR</td>
</tr>
<tr>
<td>Chlorophyll, phytoplankton</td>
<td>CIR, TIR</td>
</tr>
<tr>
<td>Vegetation</td>
<td>CIR, TIR, V</td>
</tr>
<tr>
<td>Lake/reservoir extent</td>
<td>IR</td>
</tr>
<tr>
<td>Surface temperature</td>
<td>TIR, MW</td>
</tr>
<tr>
<td>Salinity</td>
<td>CIR, TIR, MW</td>
</tr>
<tr>
<td>Oil spills</td>
<td>UV (video), TIR, MW</td>
</tr>
<tr>
<td>Waste effluents</td>
<td>CIR, TIR</td>
</tr>
<tr>
<td>Radioactive waste</td>
<td>GRS</td>
</tr>
</tbody>
</table>

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

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3.6.6 Water Pollution Studies using Remote Sensing and GIS Techniques

A project on water quality monitoring has been identified, under the Indian Remote Sensing satellite utilization program, to study the water quality conditions in the inland reservoirs namely Matatila and Ramganga and lakes namely Dal, Wular, Chilka, Kolleru and Pulicat in collaboration with the concerned state Govt. departments/institutes. Secchi disc depth distribution maps have been prepared using chromaticity analysis technique for all test sites. Mapping of different turbidity levels and distribution of aquatic vegetation has been carried out for all the test sites. 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. Significant correlation has been obtained between IRS LISS-II data and turbidity. It is noted that except for 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. In both the Hussainsagar Lake and in the Godavari river, industrial pollution and sewage have given rise to water hyacinth, hydrilla and filamentous algae (Tamilarasan et al. 1989).

Under ISRO respond program, 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). 2 modular multi-spectral scanner (M2S) and multi-band 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 analyzed digitally on the interactive M-DAS system to produce colour-coded maps of pollution parameters.
Several LANDSAT images of nineteen reservoirs in the Kansas State, U.S.A. has been examined by Yarger, et al., (1973). They have concluded that LANDSAT MSS bands and ratios can be used for reliable prediction of suspended load upto 900 ppm. 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 gray 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 that “if a ground based sampling program was developed, this procedure may be helpful for selecting lakes with widely differing physical and chemical qualities.

Development of the chromaticity techniques started using LANDSAT photographic images and then progressed to digital analysis of computer compatible tapes (Alfoldi and Munday, 1978). The basis of the chromaticity method involves the transformation of radiance values from LANDSAT MSS bands 1, 2 and 3 into a pseudo-colour plane (chromaticity space) where in normalized brightness parameters of colour saturation and hue are examined and manipulated. Extensive empirical testing of the chromaticity technique was conducted in the Bay of Fundy on the east coast of Canada (Munday, 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 these data sets were atmospherically adjusted to the ninth (the reference scene). These data were used to verify the chromaticity techniques. Correlation between satellite and ground truth data for the combined data sets (after relative atmospheric adjustments) is 96% and the absolute error of the calibrated satellite measurements is approximately 44%. Effects of sediment type and size were negligible. The system can be used to measure chlorophyll, Secchi disc and turbidity. Secchi disks were 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.

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
atmospheric conditions and different solar angles. The method is continuously used
for water quality surveillance of Swedish lakes.

Ritchie and Cooper (1987) had analyzed 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, 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 in-situ
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 scene
showed that MSS bands 2 (600 to 700nm) and 3 (700 to 800 nm) radiance or
reflectance were best correlated with suspended sediments. Various sedimentation
levels in the Ukai reservoir were identified using multidate LANDSAT MSS data
(Sahai, et al., 1983). Each band was analyzed separately using density-slicing
techniques. Later on, they were superimposed on each other, such that 10 turbidity
levels were identified.
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). CIR photographs were acquired and synchronously water samples were collected from the discharge of paper mill effluent 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 semi-emperical model. The results indicate the mixing-zone waste distributions more reliably and in detail than conventional surface measuring techniques.

The seven levels of turbidity were delineated from multiband LANDSAT images of May, 1977; June, 1978 and May, 1987 in case of Wular lake. The maximum turbidity was observed at the confluence of the Jhelum river. Interpretation of sequential LANDSAT FCC’s of 1977 (January to May) shows that the growth of aquatic vegetation viz. Trapa spp. Starts in the month of April and its growth was considerably high during May. The southern shallow water marsh region appeared as black in the LANDSAT FCC. This area is found to have been developed in the near past due to sedimentation in the lake (Tamilarasan et al. 1989).

A similar analysis was carried out using digitally generated products viz. band ratios, principal component analysis (PCA), chromaticity techniques, and classification. FCC of PC 1, 2, and 3 shows water spread and aquatic vegetation clearly in the Wular lake. Pseudocolour images of ratios B2/B1, B3/B1, B3/B2, B4/B1 etc. show encouraging results. In B3/B2 ratio image turbid water, floating aquatic vegetation and shallow water were distinct. In B4/B1, turbidity levels (3) and density of vegetation (2) were clearly observed. Six turbidity levels were identified using chromaticity technique in the Wular lake. These levels of turbidity are comparable with the visually interpreted map. The colour photographs of the lake show distribution of different types of vegetation on the surface of the water, which is represented by the hues of green colour. The clear and turbid water was delineated on
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the basis of hues of blue colour. The Secchi disc depth ranges from 20 cm to 60 cm in this lake. A total of 10 levels of turbidity and 4 to 5 types of density of aquatic plants were interpreted. The colour infra-red photographs were also used for this study (Tamilarasan et al., 1989). Digital satellite data has been used in the past to monitor pollution levels of selected parameters in water bodies (Lathrop and Lillesand, 1986, Rathore and Wright, 1993).

Using multidate and multiband data of LANDSAT MSS and TM black-and-white bands water spread and turbidity levels were delineated in Chilka lake. Turbidity levels (6 to 8) delineated using MSS and TM black-an-white images show that the northern portion has very high turbidity (0.08 to 0.1m SD). The central and the southern portions have moderate (0.7 to 1.5m SD) and low turbidity (>2m SD). This is very useful, to understand the mechanism of mixing of the sediments in the lake and its distribution. A similar study was carried out using digitally generated images viz. band ratios, principal component analysis (PCA), chromaticity analysis and classification. High turbidity is distinct in B1/B2 and B1/B4 while low and moderate turbid levels distinct in combined ratio of B1/B2, B1/B3 and B1/B4. TM1/TM4 show 4 levels of turbidity. PC 1 of MSS show 7 levels turbidity in the lake. PC 1 2 3 of TM shows three broad zones of turbidity clearly viz. low, moderate and high. Supervised classification of MSS and TM data 4 and 7 levels of turbidity respectively. A colour coded Secchi disc map was generated which show 7 classes of turbidity. This technique is found excellent in mapping Secchi disc distribution, which represents the turbidity levels in the Chilka Lake (Tamilarasan et al., 1989).

Using airborne MSS data, accurate measurement of turbidity and sediment concentration in rivers, lakes, reservoirs and the ocean is possible (Smith, 1985). Relatively poor spatial resolution of satellite data is one of the major constraints as most of the water bodies created by strip mines are small or narrow and the poor spatial resolution of satellite data is not suitable for water quality analysis. Repic et al. (1991), have used narrow band multispectral video imagery to study acidity and metal
contamination (Iron) at two water bodies at a surface coal mine in clay County, Indiana, U.S.A. Video imagery was acquired in the yellow-green (0.543 to 0.552 \( \mu \text{m} \)), red (0.644 to 0.656 \( \mu \text{m} \)) and near-infrared (0.815 to 0.827 \( \mu \text{m} \)) from an altitude of 2400 m using narrow band filters on cameras sensitive in the visible and near-infrared regions. Water samples were collected from 14 locations over the water bodies and analyzed for pH and Iron content. These sample location were then identified on the video imagery and at the each location, the mean digital value at a 3 by 3 window of pixels, (centered at the identified sample location), was calculated to avoid mislocation errors. This was done for all 14 water samples and each band and digital values, at each sample location, were correlated with the pH and Iron content at that location. Correlation results showed the yellow-green band to be positively correlated (significant at 0.05 levels), with iron concentrations and negatively correlated (significant at 0.05 level) with pH values, possibly because increased iron in solution is caused by increased acidity. It was suggested that these high correlations of the yellow-green band with pH and iron was due to the fact that the yellow-green band was more sensitive, as compared to the red on the near infra-red bands. The study conclude that the yellow-green band of the video imagery was most sensitive to pH and the iron content of surface mine water and that it can be used to monitor iron concentration and acidity in coal strip mine drainage area.

Thermal power generation of coal pit-heads and associated urbanization and closely linked with the problem of environmental degradation especially the pollution of land, air and water. FCCs of LANDSAT TM, and IRS-1A LISS II have been successfully used for the study of river pollution (Palria et al. 1995).

Rigina (1998) used a map of the Kola Peninsula (1: 1,000,000), including layers of coastline, populated places, drainage net and elevation, as a basis of GIS presentation. A geological map of the Kola Peninsula (1: 8,000,000) as well as spatial modeling results for sulphur deposition from local sources, were digitized in corresponding projection. sulphur deposition was predicted by a numerical trajectory
model for meso-scale, which took into account the locations and parameters of emission sources, the vertical structure of wind and the influence of topography.

Concentrations of water chemistry constituents were displayed as point information across the region by means of ARC/View for a single field (ANG – acid neutralizing capacity) or one field versus another [(HCO\textsubscript{3} vs. SO\textsubscript{4}\textsuperscript{2-}; (Ca\textsuperscript{2+} + Mg\textsuperscript{2+}) vs. (Na\textsuperscript{+} + K\textsuperscript{+})]. During spatial analysis, the databases on water chemistry were linked to spatial information on bedrock and modeled Sulphur deposition by means of a spatial join (point-in-polygon analysis) within ARC/View, which intersected the water chemistry point data with polygons presenting bedrock and sulphur deposition class. Statistical analysis of the information obtained was implemented using MINITAB. This study explores many approaches regarding GIS capability in water chemistry. Such as it revealed relationship between various constituents of surface water chemistry, displayed variability of surface water chemical constituents across the region and revealed sensitivity to acidification. It ascertained new relationships between constituents of water chemistry and other information about the region, available in geographical presentation. Spatial variability of major constituents of water chemistry is influenced by anthropogenic load as well as by geological and climatic factors. GIS allowed a mathematical model of spatial distribution of Sulphur deposition to be verified using monitoring data for surface water SO\textsubscript{4}\textsuperscript{2-} concentration. A high correlation between sulphur deposition and surface water SO\textsubscript{4}\textsuperscript{2-} concentration implies that pollution on the Kola Peninsula originates from local sources and that airborne pollution dominates over waterborne.

3.6.7 Marine Pollution Studies by Remote Sensing

Apart from these studies remote sensing can also be used for marine pollution studies. LANDSAT images have been very useful in these studies. Green-yellow band, (MSS-4) where water is relatively transparent, is the most useful band for underwater studies and mapping of the surface currents carrying particulate matter (Otterman, et al., 1974). Oil slicks, a main source of ocean pollution, show up darker
than the surrounding unpolluted ocean in all the MSS bands. A comprehensive survey of the methods of detecting oil spills is given by Estes and Senger (1972). They present scanner imagery of an oil slick taken with the University of Michigan multispectral scanner. In the ultraviolet and the blue spectral intervals, the slick shows up brighter in the imagery, while in the imagery above 0.52 µm there is essentially no contrast. Examination of MSS-5 (LANDSAT) positive print of Gulf of Sulz shows darker spot in two locations around the oil production platforms in the Gulf, some 6 to 12 km of the shore of Sinai. These dark spot could not be interpreted in any other way except as oil slicks. Subsequent check with the operating crew confirmed that a break occurred in an underwater pipe before that date. The radiometric characteristics of oil slicks versus the unpolluted ocean shows that the darkening is apparently due to the mechanical effect of smoothing the surface, i.e., reducing the slope of the waves and therefore the reflecting to zenith.

Bodies of water are basically dark in all LANDSAT bands because the coefficients of reflection at the surface are low at all the wavelengths. In areas that show up brighter, the light that penetrates the surface is reflected either from a shallow bottom or from particulate matter suspended in water. The intensity of such reflection from below the water surface depends on the transmission through the water, and is thus greatest in the green-yellow band, MSS-4, where water is relatively transparent. This is the most useful band for underwater studies and mapping of the surface currents carrying particulate matter (Otterman, et al., 1974). The infrared band MSS-7 is best for delineating shoreline or the extent of flooding, since bodies of water, even quite shallow, are uniformly dark in this band owing to extremely low transmission.

3.6.8 Groundwater Pollution Studies

Groundwater is an increasingly significant source of potable water and accounts for over 90% of the world's fresh water resources (Stetzenbach, et al., 1986). There have been reports of groundwater pollution in a number of aquifers
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throughout the world, and a very wide range of pollutants has been recognized.
including N species, heavy metals, chlorinated hydrocarbons, phenols, cyanide.
pesticides, major inorganic species and bacteria. Nitrate (NO₃) is the main form of N.
which occurs in groundwater and is becoming increasingly widespread because of
agricultural activities and the disposal of sewage. Solubility constraints do not limit
concentrations of nitrate in the range reported for groundwater. Because of this and
because of its anionic form, nitrate is very mobile in groundwater. In strongly
oxidizing groundwater nitrate is the stable forms of dissolve nitrogen. It moves in
groundwater with no transformation and little or no retardation (Freeze and Cherry.
1979, Kacaroglu and Gunay, 1997).

The undesirable change occurring in physical, physiological, chemical and
biological characteristics of natural waters, directly or indirectly as a result of
anthropogenic activities, leads to its pollution making it less useful and harmful
affecting human life, affecting the water resources and ultimately the living
conditions of desirable biotic species. There are many sources, which can pollute
groundwater:

- **Point Sources**: the point sources of groundwater contamination are due to
  percolation of liquid wastes, percolation from solid waste disposal sites, leaking
  tanks, animals waste etc.

- **Line Sources**: line sources may be waste leaking from sewers and pipelines.
polluted streams and liquid waste disposed to dry stream beds.

- **Diffuse sources**: these include septic tanks, agricultural return flow, fertilizers
  etc. the effect of specific waste discharge on quality of groundwater and surface
  water depends on the area, extent and configuration of discharge at land surface.
  Various pollutants from different sources may be characterized as physical,
inorganic, organic, bacteriological and radiological. Principal human activities
viz. urbanization, industrialization, agriculture and mining development are
principal causes of groundwater pollution.
There are many reports which indicate that groundwater is polluted by (a) recharge of the groundwater via infiltration from the river and irrigation channels, (b) infiltration of municipal waste water into groundwater from septic tanks, and (c) agricultural activities (irrigation and fertilizer application) (Kacaroglu and Gunay, 1997, Rao and Prasad 1997, Berka, et al., 2001). Most of the higher levels of nitrate are found in groundwater, as nitrate in surface waters tends to be depleted by aquatic plants (WHO, 1984).

The quality of groundwater in the case of open drinking water wells is affected near mining areas because of air pollutants such as dust from dumps, stockpiles and transportation of ores. Again water stored in the open pits after the closing of the mine can be contaminated by particulate, into the ground and pollute groundwater. Also, the concentration level of different chemical components in soil and water vary with respect to diurnal changes as well as seasonal variations in the water flow and quantity of atmospheric fallout etc (Ratha and Venketaramnan, 1997). Considerable spatial and seasonal variation occurred in bicarbonate (the major ion in the groundwater) and in electrical conductivity. Both parameters were generally higher in wells adjacent to the trees than in the grassy areas (Hoyle, 1990).

Yates (1985) states that septic tanks are the largest contributors of wastewater to the subsurface. Improper construction, siting, installation, and maintenance of the septic tanks, as well as factors such as depth to groundwater, climate, geology of the site, and septic tank density influence the potential of septic tanks to pollute groundwater. The improper location of wells with respect to septic tanks will increase the potential for the leaching of effluents to the well and groundwater system (Piskin, 1973, Alhajjar, et al., 1990).

In irrigated areas, salts and trace elements can be problem. The major non-point source of groundwater contamination is nitrate and pesticides. Sallow
groundwater is most vulnerable, but deep groundwater can also be affected. especially by the more mobile agricultural chemicals such as nitrate and pesticides with a high water solubility and a long life (Anonymous, 1990).

Groundwater systems are three-dimensional and have heterogeneous physical and chemical characteristics. Thus, the chemical characteristics of groundwater samples have to be interpreted in the context of the three-dimensional flow system and the sources of water flowing to the sampling point. To accurately interpret those characteristics, it is important to know where the water come from, the geological material it has traveled through, and the time of travel from the source (Acharyya, et al., 2000; Subrahmanyam and Yadaiah, 2000; Anonymous, 1990). The occurrence, movement and control of groundwater, particularly in hard-rock areas, are governed by different factors such as topography, lithology, structures like fractures, faults and nature of weathering (Raju and Reddy, 1998).

Relations of shallow groundwater quality to land use were tested statistically by using data from wells located in or near the outcrop areas of the Potomac-Raritan-Magothy and the Kirkwood-Cohansey aquifer system in the New Jersey coastal plain. Water samples from both unconsolidated aquifer systems in undeveloped, agricultural, and urban land use settings were analyzed for major ions, nutrients, trace metals, volatile organic compounds, and pesticides residues. Percentage of land use categories within fixed radius buffer zones centered on the sampled wells were calculated by using digital land use and land cover data. Nonparametric statistical techniques were used to compare the relations between water quality constituents and land use. In both aquifer systems, statistically significant differences (alpha ≤ 0.05) in water quality with respect to land use were determined for nitrate, volatile organic compounds, and pesticides. Nitrate concentrations were significantly higher in groundwater beneath agricultural and urban land than in groundwater underlying undeveloped land. Volatile organic compounds were detected more frequently in groundwater underlying urban and undeveloped land than in groundwater beneath
agricultural land. Pesticides residues, however, were detected more frequently in groundwater underlying agricultural land than in groundwater beneath undeveloped and urban land. Statistical results were similar for the two-aquifer system, indicating that the methods applied in this study are transferable to the other areas with similar hydrogeology, climate and land use (Anonymous, 1990).

The occurrence, movement and control of groundwater, particularly in hard-rock areas, are governed by different factors such as topography, lithology, structures such as fractures, faults and nature of weathering (Raju and Reddy, 1998). The solubility of gypsum is generally very high in comparison to many other minerals. The surface and groundwater containing gypsum formation can easily attain high amounts of total dissolved solids (TDS), calcium and sulphate (Kacaroglu, et al., 2001).

It is found that local bedrock is the dominant source of trace elements found in groundwater (Pelig-Ba, 1998). The presence of biological contaminants, P and detergents in the groundwater indicates that it may have been contaminated by waste water (Huizar-Alvarez, 1997. Weng and Chen, 2000). Leachate from solid waste also contaminates both groundwater and stream waters, particularly with some heavy metals (Whalley, et al., 1999). Lead contamination of groundwater could be associated to the seepage of irrigation water, corrosion of buried metallic structure (largely of iron), and leachate from the industrial dust pile. Salinity plays major role in determining chemical forms of Pb in groundwater. Over 80% of the total Pb water was present in Pb-Cl complexes in groundwater samples with salinities > 4C ppt (Sadiq and Alam, 1997). Unconfined aquifer (alluvial deposits and schists), are highly polluted, due to mining activities.
3.6.9 Mapping of Groundwater Salinity using Remote Sensing Techniques

Quality deterioration of groundwater is also documented and attributed to seawater intrusion in coastal freshwater aquifers and nitrate pollution of agricultural origin (Stamatis, et al., 2001). Electrical resistivity techniques have been used successfully for the delineation of salinity estimates of groundwater on a local basis only. For regional studies, these techniques are neither cost nor time effective. Soil and vegetation conditions, together with morphological characteristics, reflect the groundwater situation in a terrain, and they can be employed for the estimation of the depth and quality of near surface groundwater. The integration of remotely sensed data and use of GIS can serve as a useful guide for the selection of training areas for classification, and to update a data base for the assessment of spatial and temporally dynamic phenomena (Walsh, et al., 1990). Further, inferential methods using GIS for depth and quality estimates are required, in the case of groundwater occurring at greater depths.

The use of thematic overlays as an aid to the interpretation of remotely sensed data is not widely utilized, although its application has great potential (Sharma and Anjanevultu, 1993). The main causes of saline soil hazards are groundwater at or close to the surface and high air temperatures. The surface expression of the terrain, in terms of soil and vegetation, can be analyzed distinctly on a satellite image. As a total plant cover in a given area is a more reliable groundwater indicator than the individual plants (Kruck, 1976), the general vigour of growth of plants, as represented on a satellite image, has been found more useful for the uniform and regional evaluation of groundwater depth. A study on the basis of vegetation is valid since the scattered vegetation on the ground will appear denser on satellite image, due to the smaller scale (Bajpai and Gokhle, 1991).

Reflectance variations of vegetation on the image are attributed to the different species of vegetation and their densities, which together provide evidence of shallow groundwater conditions. Favourable growth conditions prevail in regions
where the water table is situated below the area of influence of evapotranspiration, that is, within 10m depth (Kruck, 1976). These regions appear predominantly darker in band-4 and lighter in band of IRS-1B, indicating a dense coverage of vegetation with a high chlorophyll content. Since the surface signature investigated on the image are due to the net effect of groundwater condition and vegetation, band-4 was found to be more useful than any other band. Areas having brackish groundwater and saline soils associated with a high water table promote unfavourable growth conditions for green vegetation, and it has been observed (Murty and Srivastava, 1990) that band-3 proves more sensitive due to less absorbance in the red wavelength region of the electromagnetic spectrum. An indication of water scantly vegetation in an area is due to the depth of salinity of groundwater can be confirmed using band-4, on which regions of high salinity appear lighter. The green vegetation index (GVI) is used by Srivastava (1997), since it represents the normalized differences in spectral reflectance between the near infrared (NIR) and red band (R) which emphasize the vegetation vigour (Jenson, 1986), and can be expressed as.

\[
GVI = \left\{ \frac{(NIR-R)}{(NIR+R) \times 127} \right\} + 128
\]

Table 3.4 Salinity Indication on Satellite Imagery

<table>
<thead>
<tr>
<th>Zone</th>
<th>Reflectance zone</th>
<th>Image indication</th>
<th>Hydrogeological conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>Low salinity zones</td>
<td>Large bright patches representing dense vegetation</td>
<td>Depth to groundwater within 30m. Normal salinity. Chloride content &lt;180 ppm.</td>
</tr>
<tr>
<td>(2)</td>
<td>Medium to low salinity</td>
<td>Scattered small bright patches with sparse vegetation.</td>
<td>Depth to groundwater &lt;20m. Chloride content between 200 to 180 ppm.</td>
</tr>
<tr>
<td>(3)</td>
<td>High salinity zones</td>
<td>Dark patches due to absence of dense vegetation.</td>
<td>Depth to groundwater between 1.5 to 7.22m. Chloride content &gt;210 ppm.</td>
</tr>
<tr>
<td>(4)</td>
<td>Ravenous/sandy Zones</td>
<td>Dark patches along the surface stream.</td>
<td>Depth to groundwater very near to the surface.</td>
</tr>
</tbody>
</table>
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Reflectance zoning was obtained on a regional GVI map, which offers an effective enhancement of the various salinity zones for this type of interpretation. The reflectance response in the GVI image, with the vegetation characteristics and hydrogeological conditions are given by Srivastava, 1974, and Ahmad, 1984a.

Srivastava, et al., (1997), have obtained similar types of zones. A reflectance map of the area was prepared on the basis of the variance in reflectance of the various vegetated areas. The contour map of chloride concentrations in groundwater was digitized. This map was used to register the imagery. Geometric rectification using eight ground control points and nearest neighbour resampling of the image was performed. The location for different levels of salinity points was taken from the digitized map and their corresponding locations in the satellite image recorded. The location and their salinity values were used to classify the image using the point samples collected from digitized map, and the reflectance zonal map of the area has been prepared using ILWIS 1.41. This map showed a close conformity with the actual groundwater salinity conditions in the area.

3.7 AIR POLLUTION STUDIES

Atmosphere is a protective blanket of gases, surrounding the earth, which sustains life on earth. The atmosphere is composed primarily of Nitrogen (78.08%), Oxygen (20.9%) and several other inert gases. Because of various industrial processes, air pollutants such as Sulphur dioxide, Nitrogen dioxide, Carbon monoxide, Ozone, Hydrocarbons, Suspended Particulate Matter, etc. are continuously added into the atmosphere which change the composition of air and affects the biotic environment.

Air pollution in urban areas arises from multiple sources, which vary from location to location, within a geographical site. The concentration of air pollutants depend not only the quantities that are emitted from air pollution sources but also on
the ability of the atmosphere to either absorb or disperse these emissions. The air pollution concentrations vary temporarily causing the air pollution pattern to change with different locations and time. The ambient air quality is dynamic and complex environmental phenomenon exhibiting large temporal and spatial variations due to changes in meteorological and topographical condition (NAAQMS/21/2001-2002).

For a comprehensive pollution investigation, one needs to examine not only the pollution distribution but also the geographical distribution of its causes and of its consequences on the environment. Data on these phenomena should be spatially resolved and form thematic layers comparable and easily updated. This is precisely the role of GIS (Geographic Information System), which is a powerful set of tools for storing, retrieving, transforming and displaying spatial data from the real world. Especially, geographical data handling is a very crucial issue, because, database creation is an exceedingly complex task, involves many steps, and requires great care, skill and experience if the result is to be satisfactory.

Pixel size plays major role in this method of study. The value borne by a pixel is a non-linear average of the radiances emitted by the very elements composing the pixel: pavement, streets, buildings (wall, roof, different materials etc.), trees, other vegetation, vehicles, etc. If the pixel size is much larger, then this value does not necessarily represent the value measured by the station, which is usually like a pin-point, particularly if this station is located close to the border of the pixel. The larger the pixel, the greater the discrepancy between satellite-derived temperature (or any other parameter) and the ground measurements. The magnitude of the discrepancy is probably a function of how great the pollution is and how large its spatial extension is. The better results can be obtained using the highest spatial resolution.
3.7.1 Theoretical Background

Networks of instruments have been established in major cities. They are composed of a few measuring stations and are a means for alert. Air quality is highly variable within a city. It is namely but not uniquely a function of the intensities of the air turbulent diffusion around the pollution sources. These sources can be mobile, as it is the case of cars. The ventilation is a function of the wind direction; it follows that a street may be occasionally ventilated or not (Wald, et al, 1999).

Satellite and, in general, all remote sensors provide information on matter by measuring its interactions with the Electro Magnetic Radiation (EMR). The following attractive features in the context of air pollution investigations:

- Contrary to conventional means allowing point measurements only at ground level, EMR provides a more representative coverage between two points along the observation path;
- EMR does not perturb the natural flux of the pollutants as no probe is used, neither is transportation of air samples required;
- There is security in the case of monitoring of dangerous substances and information can be provided for not easily accessible areas of the globe.

Despite the above advantages, remote observations are feasible only if the explored interaction mechanisms between EMR and the atmosphere are:

- Strong enough to be observable;
- Isolated enough from other contaminating signals;
- Sensitive enough to detect variations in the parameter of interest.

For example, while a range of satellite instruments monitor atmospheric ozone, the abundance of stratospheric compared to tropospheric ozone makes it difficult to use satellite for measuring variations of the latter. Furthermore, scattering
and reflection by aerosols and clouds, and the existence of large spectral bands of absorption by water vapour and carbon dioxide make it even more difficult to monitor gaseous pollutants by EO. Another practical limitation is the maximum weight that can be launched. This has been obstacle for launching Lidars in space despite their advantage of spectral purity in air monitoring.

Some LSR sounders (i.e. non-imaging instruments) and spectrometers on board meteorological satellites provide analytical data on atmospheric gases but they function either in a limb mode (off–nadir observations) and peer the upper atmosphere, or/and they attain low horizontal resolutions suitable only for global studies. This is because incompatibility exits between high spatial resolution and the high spectral resolution required for measuring isolated trace gases.

HSR and MSR sensors are sensitive to the so-called optical spectrum, which extends from approximately 0.3 to 14µm. This range includes UV, Visible, near-mid and thermal infrared wavelengths and is termed “optical” because lenses and mirrors can be used to refract and reflect energy. In this spectral domain, the signal recorded by the sensors is emitted or reflected by the earth and the atmosphere. A change in the composition of the atmosphere (by the presence of pollution) modifies the signal through interaction mechanisms between radiation and the atmospheric components. These interaction mechanisms induce optical atmospheric effects on the images that may affect the signal recorded by the sensor in two ways: geometrically or radiometrically. Geometric modifications are due to light refraction and are not intense enough to be observable by satellite sensor. Radiometric modifications are linked to light absorption, scattering and backscattering caused by atmospheric molecules and particles.

The use of the particulate extinction coefficient or of its linear integral, i.e. the optical thickness is an appropriate in air pollution measurements because:
The problem of particulate pollution is very sensitive at present especially after new scientific evidence on health effects of small particles.

The presence of particles in the atmosphere always causes a reduction of the extinction coefficient. This reduction is strongly correlated with the concentration of small particles (Horvath, 1981, Waggoner, et al., 1981).

In photochemical pollutions light extinction is due to particles, while only the yellow-brownish colouration of the smog is due to NO₂ (Waggoner and Weiss, 1985).

The magnitude of the extinction varies according to the different spectral bands of the EO sensor used. In the UV spectral domain the atmosphere is practically opaque due to Rayleigh scattering and ozone absorption, and in the near-infrared is too transparent for pollution observations. The visible domain is most appealing for evaluating optical atmospheric effects of pollution. The mid-infrared can be used to distinguish hot pollution sources (e.g. actively burning fires) inside an observed haze, and the thermal infrared can be taken into account to increase confidence in pollution mapping.

3.7.2 Air Pollution Studies by Remote Sensing and GIS Techniques

The most widespread applications of satellite remote sensing or Earth Observation (EO) are certainly weather prediction, mineral exploration and crop forecasting. EO both, manned and unmanned spacecrafts has also added a new dimension to better understanding the natural processes on our planet and the anthropogenic impact on its fragile interconnected environmental resources. In the context of direct pollution observations and mapping, on local and regional scales, the derivation of spatially resolve data is necessary. In this context, the various EO systems are classified according to their geometric or spatial performances into:

- LSR: Low Spatial Resolution satellite sensors (i.e., tens to hundreds of km). These include TOVS (NOAA) and TOMS (ADEOS, NOAA, Earth Probe).
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- MSR: Moderate Spatial Resolution satellite sensors (i.e., few km). Examples of these include AVHHR (NOAA), ATSR (ERS-1, 2) and imagers on board geostationary satellites;

- HSR: High Spatial Resolution satellite sensors (i.e., tens to hundreds of meters). These include HRV (SPOT), TM/MSS (LANDSAT), OPS (JERS-1), SAR (ERS Series, JERS-1, SAR-10, SAR-70), MESSR (MOS), LISS-1 (IRS) and MSU (Resurs). In this category are included very high-resolution sensors (i.e., better than 10m), such as the Russian DD-5 systems (KVR-1000, TK-350) and commercialized military data.

The observational capabilities of EO systems depend also on the spectral and radiometric specifications of the system and on the orbital characteristics (defining the temporal resolution) of the satellite platform.

The contribution of EO satellites to the atmospheric dynamics and weather prediction is well established by the meteorological satellites or meteosats. EO currently provide, on an operational basis, MSR data on parameters, which are very useful to air pollution investigations:

- Imaging sensors such as MVIRI, VISSR and VAS on board the geostationary Meteosats 3-7 (Europe), GMS (Japan), GOES (US) respectively, provide data on wind field, cloud cover, water vapour and sea surface temperature every 30 min.

- Sounding instruments, such as HIRS2, SSU and MSU on board the in-polar-orbit NOAA (US) provide data on temperature profiles, humidity, water vapour and precipitation every 6 hours in average.

Some of the previous parameters will be measured with improved accuracies (e.g., better vertical resolution) by the next generation of instruments, e.g., temperature profiles by IASI (Europe) and AIRS (US). Further improvement is
envisaged with the use of active instruments e.g., DIAL Lidars, proposed for past-200 missions (e.g., BEST by France) that would also be capable of trace-gas profile measurements.

At present, no EO sensor can provide direct information on gaseous pollutants. (e.g., CO, NOx, SO2, CH4, O3) in the lower troposphere. It is only with future sensors such as MOPITT on EOS-AMI (US, 1999), TES on EOS CHEM-1 (US, 2002) and SCIAMACHY on POEM-I (Europe, 1998) that such measurements will be possible. These sensors will be, nonetheless, measure, with horizontal resolutions of tens to hundreds of kilometers, suitable for macroscale modeling rather than for urban/local observations, despite the lack of direct measuring of pollutants from space, these can be detected, as described in the previous section, by their optical effects on EO images.

The wavelength dependence of the optical effects of pollution allows the detection of much more tenuous pollutions, that is, smoke wreath from factories, or urban hazes. It also allows the differentiation of pollution from natural clouds. Similarly, the pollution effects are more apparent on certain band combinations (called colour composites) than on others and this permits the delineation of polluted areas and the localization of emission sources, throughout photo-interpretation of HRS images. The detection of pollution plumes over water is easier because of the strong backscattered radiation in the near infrared, where the water reflectance is minimal.

A more quantitative evaluation of the pollution levels can be carried out by examining the scatterograms of images, by applying textural analyses or, by using inverse radiative transfer modeling. The latter is normally used as a “haze compensation” procedure since the atmosphere, and a-foritiory pollution, introduce noise to the Earth’s useful signal. Different methods deal with the isolation of this
pollution noise, in terms of particulate optical thickness, depending on the spectral bands and the kind of terrestrial target observed. The "ocean method" is applied above clear water, using visible or infrared EO data (Griggs, 1975), the "brightness method" is applied above land or water features and uses data in the visible spectrum (Fraser, et al., 1984), the "contrast reduction method" is applicable over land (Tanre, et al., 1988) or over mixture of land with water (Kergomerd and Tanre, 1989), finally there is a method the "dark vegetation method" applicable exclusively over vegetation feature using long wavelength visible data (Kaufman and Sendra, 1988). These methods are implemented on the spatial domain of the images (i.e., the x, y coordinate space). Other procedures can be applied in an alternative domain namely, the frequency domain (i.e., where an image is separated in its components through application of the Fourier transform. Theoretically, all the previously mentioned methods could be applied to EO data from all HSR sensors, although the limited existing experience concerns mainly LANDSAT and SPOT.

Holben, et al., (1992) have reviewed these procedures and their limitations. In order to apply any of these methods, with the exception of the 'ocean method' one needs to compare optical data sets and estimate variations of the observed radiance values. The assessed optical thickness is then relative to pollution free conditions and is a linear function of the particulate content, practically concentrated in the lower troposphere, since optical effects by aerosols are virtually determined within the first kilometer(s) of the ground (Fraser, et al., 1983). A limited number of forthcoming EO imaging systems are foreseen to monitor directly the aerosols in the troposphere. these are:

- Passive systems, including: POLDER, a polarization radiometer on ADEOS (late 1996) and BEST (2000); MODIS, a 36-band imaging spectrometer with 250m to 1 km resolution, and MISR, a 4-band CCD arrays providing 9 separate view angles, on EOS-AM1 (1998); HIRIS, a 192-band imaging spectrometer with 30m resolution, on EOS-AM2 (2003);
- Active systems, including the ATLID laser radar on post-2000 ESA missions.
Routine observations made by the environmental satellites are certainly a valuable aid in improving the actual methods of mapping. Some studies have been made using such data. Most of them deal with the urban heat island (Kim, 1992, Henry, et al., 1989, Hyoun-Young Le, 1993, Quattrochi and Ridd, 1994. Roth and Oke, 1989). They mostly consist in mapping the radiance sensed by thermal instruments onto a map of the city. Such instruments are intended to measure the temperature of the surface of the objects. The heated urban islands then appear a hot anomalies compared to the islands that are not an indicator of the air pollution but do favour it. Urban sink is less common phenomenon and consists of an urban area cooler than the surrounding rural area. It has also been observed by satellite (Carnahan and Larson, 1990).

A decrease in the atmospheric transmission factor caused by the appearance of a pollution layer (more absorption and scattering) results into a decrease in the temperature observed by the space-borne sensor (McLellan, 1973). Some studies have been made along these lines. They make use of images acquired by the LANDSAT TM sensor. This sensor has several bands (TM1 to 7); all of them but one are in the visible or near-infrared range with a spatial resolution of 30m. The thermal infrared band (TM 6) has a spatial resolution of 120m, four times less than that of the other bands. The sensor outputs in this band are calibrated in radiance by the means of in-band calibration systems. These radiances in turn transformed into apparent temperatures at the top of the atmosphere. It should be noted that the digital numbers output from TM 6 are opposite to the apparent temperatures: the colder a given surface, the smaller the apparent temperature, and the larger the digital count in TM 6. LANDSAT images are acquired at 10:30 a.m. mean solar time. in clear sky conditions. This hour is rather suitable for this kind of investigation. Strong isolation has not yet warmed too much the objects, the night cooling has already passed and objects within the cities tend to have rather similar surface temperatures.
Poli, et al. (1994) have studied the relationship between a map of apparent temperature of Rome (Italy) and the total particulate matter suspended in air (PTS) in winter season. The PTS as well as the sulphur dioxide have been measured at five locations and daily added up. The particulate matter is assumed to be a significant indicator of the atmospheric pollution as well as a good tracer of the air quality. Noticeable number of the pollution has been observed for the day under concern. They found a strong negative correlation (-0.97) between the satellite derived and the PTS. Confidence level for this coefficient is well above 95%. On the contrary, the correlation between the sulphur dioxide and satellite derived temperature was weak and there was no significant relationship.

Finzi and Lcchi (1991) analyzed two LANDSAT images of Milan (Italy) and compared them. The first one is dated 20 January 1983 and was taken during clean conditions. The second is dated 27 January 1986 when pollution reached critical levels. Though the $SO_2$ itself is transparent in thermal band, it is usually associated with NOx, particulates and aerosol, giving a combined effect of opacity within the atmosphere. Hence the authors considered the $SO_2$ concentration as a good tracer of the global urban air pollution level. Ten ground stations were considered, each supplying $SO_2$ concentrations every 30 minutes. Prior to analysis they have aggregated the TM 6 pixels into large polygons, one per station, covering the city. For the unpolluted day, the correlation coefficient between the $SO_2$ and the satellite apparent temperature is very low (0.48). For the polluted day, this coefficient is (-.0.84). However, a close examination of their finding shows that these results are partly contradictory and that no definite conclusion can be drawn.

Wald, et. al. (1999) have done air quality observation over the city of Nantes (Western France) using LANDSAT Thermal infrared data. They compared ground measurement of black particulate, sulphur dioxide and other pollutant with coincident LANDSAT TM 6 data. They found a very high and significant correlation (0.95) between the BP (Black particulate) and the apparent temperature with confidence
level of 95%. A high correlation coefficient (0.86) is also found with the daily averaged $SO_2$ but with a lower confidence level (85%). It should be noted that a link between apparent temperatures and the $SO_2$ is larger on a daily basis than on an instant basis (correlation is only 0.67). This is also true for the $NO_2$ and NO; the correlations are weak in both cases. They concluded that the mapping of the BP is possible using the TM 6 image. This mapping is not very accurate; the relative rms is about 80%. A fusion of the estimated map and of the few measuring stations will likely to improve results.

Wald and Baleynaud (1999) found similar results for the same city, using LANDSAT TM 6 data. Locations of the pollution measuring stations were reported onto a digital map of the streets of Nantes. This map was superimposed onto the LANDSAT image. The TM 4 channel was used for the processing because it clearly exhibits the network of streets. From TM 6 the digital counts were extracted corresponding to the stations as well as their vicinity (radius of about 100m). To each station was attached a score summarizing the quality of the extraction. To local heterogeneity of the digital counts and the vicinity of the measuring instrument have been taken into account to establish that once the 14 TM 6 digital counts had been extracted, they were compared with the measurements of the time of image acquisition by the satellite. An apparent formula was computed with the following formula:

$$TM 6 \text{ apparent temperature} = 170 - TM 6 \text{ digital count}$$

This formula is arbitrary and simply intends to obtain values, which increase with apparent temperature and not opposite, like the TM 6 digital count. The unit is arbitrary.

Wald and Baleynaud (1999), assumed that the pollution plays a major role in the pattern of temperature, two processes occur simultaneously which explain the relationship between the BP and the apparent temperature. The appearance of
pollution layer (more absorption and scattering) results in a decrease in the atmospheric transmission factor. On the one hand, this decay leads to decrease of the solar radiation impinging on the ground. The solar heating is thus decreased as well as the resulting temperature of the surface. Hence the emitted radiance is lower, and the signal sensed by the satellite is lower. On the other hand, this pollution layer absorbs as well the emitted radiance, causing a depletion of the upward radiance. This is the second process explaining the relationship. Both process contribute to the decrease of the apparent temperature as the pollution increases.

Sifakis, et al., (1998) have quantified urban air pollution in terms of atmospheric turbidity using LANDSAT-5/TM data, which were acquired under clear atmosphere and pollution condition, over Greater Athens Area (GAA). This area is known for pollution due to emissions from transport, various industries and domestic heating systems, there are difficulties in mapping the geographical distribution of pollution solely through the ground network of monitoring stations. LANDSAT-5 satellite data were selected according to the representativeness of pollution levels recorded by the local monitoring network, and standard criteria for image quality and cloud cover. Preprocessing of the image was initially performed, aiming to render them radiometrically comparable – an absolute calibration, that is, transformation of digital numbers (DNs) to apparent radiance values ($R^*$) was applied to all but the thermal infrared band. Second step was a geometrical control and subsequent correction in order to superimpose the images on a 1:50,000 scale topographic map. The final step of the processing was the application of the SMA (Satellite Mapping of Aerosols) code to the images. This was applied in two phases. The first, the values of the observed optical thickness were retrieved above the ground by application of the contrast – reduction evaluation in the visible spectrum. This was carried out according to a grid of 450m by 450m applied to the images. This grid dimension proved to be an optimum comprise: it is large enough to include some visible ground structure and sufficiently small to allow consideration of a homogenous atmosphere inside the grid. The second spectral band (i.e. green) was chosen for the extraction of $t_0$, despite the great magnitude of $t$ in the first band (i.e. blue), because the latter
spectral region is predominated by variation in molecular scattering. Subsequently, the code compared the images locally and maintained only those classes of that had been derived from pixels meeting both the criteria. And finally satellite pollution map were obtained, after the application of SMA code. The satellite pollution maps provide a general view of how the urban pollution plume spreads over the Athens basin and, in combination with available meteorological data; help explain the spatial distribution of aerosol concentrations at single points in time.

The representative of certain monitoring stations is disputable due to their location. On the other hand, the ground measurements provide information concerning only the surface level, neglecting the aerosols concentrations in higher altitudes. Airborne and spaceborne remote sensing techniques allow a macroscopic and global view of the pollution palls that completes the more accurate analytical but yet isolated conventional measurements (Sifakis, 1991). The high spatial resolution sensors on board the SPOT-1, and LANDSAT-5 satellites in the polar-orbit were scrutinized in order to evaluate the atmospheric turbidity due to the pollution palls over the Attica. The images selected for this purpose correspond to representative dates according to the pollution state of the atmosphere. Thus, the days with high or moderate pollution, and days without pollution, were chosen for the study. The processing of data was performed by applying visual, digital and hybrid method, all based on the assessment of the optical atmospheric effects, namely: the contrast reduction or the so called blurring effect, and the apparent i.e. observed by the satellite-reflectance modification. The quantities used to specify the aerosol content were the optical depths of particulate scattering and of particulate absorption (Tanre et al., 1988). The results of the optical depth quantification based on satellite images, was similar to that of previous study done by other workers with ground observations (Sifakis, 1991, 1995).

Keller and Lamprecht (1995) have shown that using multi-spectral SPOT imagery one can identify and quantify dust deposition pattern along a highway. They
have found that spatial dispersion of the dust on both sides of the road (Dalton highway) was distinctly visible in the XS3 channel (0.79-0.89μm) of a SPOT satellite image.

Otterman, et al. (1974), using LANDSAT image, showed two smoke plumes originating from two points some 3 km apart, which merge and spread downwind for about 100 km, and broaden to some 2 to 3 km, from Northern most oil production platforms, over the Gulf of Suez. The direction of the plumes follows the prevalent wind direction. They also detected another plume some 20 km long originates from a flare at a Southern production platform.

Ohring, et al (1973) addressed the question of the detection and measurement of the concentration of the gaseous pollutants that locally or regionally can be a significant threat to the environment. They discussed the following pollutants: SO₂, NH₃, CH₄, N₂O, NO₂ and H₂S. They concluded that monitoring of SO₂, NH₃, N₂O, and CH₄ from satellite platforms is basically feasible at least in the serious cases of pollution (i.e., where the product of pollutant concentration and height is large).

Black and white, colour infrared images can detect smoke plumes, and colour photos are sensitive to atmospheric haze such as smog. These images can show, for example, those areas most subject to acid rain as a result of coal burning mills or power plants. None of the sensors can detect or identify clear gaseous emissions such as volatile organic compounds from factories or plants. There are some non-imaging instruments available and other in development that might detect and possibly identify fugitive emissions. Non-dispersive Infrared Spectrometry (NDIR) can be used to detect carbon monoxide and carbon dioxide in vehicle exhaust. An infrared source (heating element) is placed on one side of the road, and an IR detector is placed on the other side. When a vehicle passes through the IR beam the instrument measures the strength of the absorption for carbon monoxide at 4.3 microns and
carbon dioxide at 4.6 microns. The ratio of carbon monoxide to carbon dioxide can be used to calculate emissions in terms of percent or grams per gallon. Similar absorption bands exist for hydrocarbon vapours such as benzene, toluene, xylene, and other aromatics. The signal to noise ratio is the major problem in the development of these hydrocarbon detectors (Prost, 1994).

Fourier Transform Infrared Spectroscopy (FTIR) is being used by several companies to detect both hydrocarbon and nitrous oxide emissions. LIDAR (Light Detecting and Ranging) has been used to measure movement and concentration of urban air pollution and to determine the composition of emissions near industrial plants. The technique consists of projecting a short laser pulse followed by reception of reflected or re-emitted radiation from atmospheric constituents such as molecules, aerosols, clouds or dust. The incident radiation interacts with these constituents and causes a change in intensity and wavelength. There are several types of Lidar systems. The most commonly used systems for pollution detection include Atmospheric Backscatter Lidar (ABL), Differential Absorption Lidar (DIAL), and Fluorescence Lidar (FL). Atmospheric Backscatter Lidar is the most common type, consisting of a non-tunable high-power pulsed laser. The system transmits at one wavelength and detects changes in the backscatter due to aerosols and dust in the atmosphere. This is used to track turbid effluent and gas plumes, among other things. DIAL measures the concentration of molecular species in the atmosphere by transmitting in two wavelengths, only one of which is absorbed. Molecules studied using DIAL include SO2, NH3, O3, CO, CO2, HCl, NO, N2H2, and NO2. Fluorescence Lidar uses two wavelengths and a spectrometer to separate the wavelength shifted fluorescence from the strong atmospheric (Rayleigh) backscatter. The laser is turned to the absorption band of the molecule of interest, and reradiated fluorescence is detected by spectral filtering of the returned radiation. Fluorescence is greater in the ultraviolet than in the IR, but for some applications this limits the effectiveness of the system because the detector is overwhelmed by normal solar background radiation. Thus, the system works best at night and when tuned to wavelengths less than on
so far it has been used to detect atmospheric trace metals including Na, K, Li, Ca and hydroxyl ion (Prost, 1994).

None of these instruments are traditional remote sensing, in the sense that they do not generate map-like images. They are included here because traditional remote sensing techniques have not been developed to monitor most atmospheric pollutants (Prost, 1994).

During the last five decades a series of ozone measurements in the atmosphere have been obtained by using in-situ and remote sensing instrumentation. The in-situ measurements were mainly performed by using balloon sounding (i.e. ozonesondes) and rocketsondes. While the remotely sensed measurements were made by using both ground-based and space-borne instrumentation (i.e. spectrophotometers) (Varotsos et al., 1994).

The most important gaseous minor constituents in the Earth's atmosphere absorb significant amounts of both solar radiation and terrestrial radiation, thus considerably modifying the radiation field and temperature structure within the atmosphere. Because of these strong absorption and emission bands remote sensing experiments to measure their distribution are possible. Remote sounding of minor constituents may be carried out either by observing their absorption of solar radiation transmitted or scattered by the atmosphere or by making measurements on their emission bands in the infrared. For instance, the TIROS Operational Vertical Sounder (TOVS) which is a set of three instruments (the High-Resolution Infrared Sounder (HIRS 2), the Stratospheric Sounding Unit (SSU) and the Microwave Sounding Unit (MSU) is used to provide temperature sounding of the atmosphere by observing the emission from CO₂, H₂O, N₂O or O₃. In 1978 and 1979 the Limb Infrared Monitor of the Stratosphere (LIMS) instrument was flown on Nimbus-7 to carry out observations by CO₂, HNO₃, O₃, H₂O and NO₂. Finally, the Stratospheric IR Interferometer
Spectrometer (SIRIS) has been used to measure the spectra of a number of stratospheric species including O₃, CFCs and nitrogen compounds. Especially the region from 1125 to 1425 cm⁻¹ has been used to derive concentration distributions for O₃, H₂O, CH₄, N₂O and N₂O₅ in the 12–40 km altitude region (Varotsos and Cracknell, 1994).

One of the ways of detecting total ozone content in the Earth’s atmosphere is by means of satellite measurements. Such measurements have been made by the Total Ozone Mapping Spectrometer (TOMS) on Nimbus-7 and TOM on Meteor-3 since late 1978. The TOMS instrument observes at six wavelengths lying in the ultraviolet (UV) wavelength range and four of these are used in pairs for the total ozone measurement. It exploits the wavelength dependence of the Earth’s UV albedo in the wavelength range from 312.5 to 380 nm (Varotsos and Cracknell, 1993, 1994, 1998; Varotsos et al., 1994, 1998; Cracknell and Varotsos, 1994; Cracknell et al., 1994).

The daily total ozone measurements over the Athens made by the TOMS instruments mounted on Nimbus-7 from November 1978 to April 1993 showed a significant negative trend. Also, a linear regression analysis for each month as well as for the whole period showed that the total ozone depletion over Athens is significantly larger than expected from models. There was strong seasonal variation from more than 6% in winter and early spring to about 1.5% in summer (Varotsos and Cracknell, 1998).

The Dobson Spectrometer has been the standard instrument for making atmospheric total ozone measurements since its development by G.M. Dobson around 1927. The global network of Dobson spectrometer data now provides calibration and validation for satellite ozone instrumentation. The Dobson spectrometer uses two monochromators, with one monochromator being used to disperse the radiation and the second one being used to reject interfering scattered radiation. By using direct
sunlight the total ozone observations are usually made on the AD double-pair wavelengths, where the A pair is at 305.5 and 325.4nm, while D pair is at 317.6 and 339.8nm (Varotsos and Cracknell, 1994; Varotsos et al., 1994, 1998; Cracknell et al., 1994, 1998).

A number of factors influence the accuracy of Dobson spectrophotometer ozone measurements. The most important factor, especially at stations located in an extremely polluted atmosphere, results from interfering absorbing gases such as SO$_2$ and NO$_2$, because these species poses absorption spectra in the region of the Dobson instrument wavelengths (Varotsos and Cracknell, 1994; Varotsos et al., 1994, 1998).

The Solar Backscatter Ultraviolet (SBUV) instrument allows for measurements of solar UV radiation within the range of wavelengths from 256 to 340nm. Solar UV radiation reaches the instrument after being backscattered by the Earth’s atmosphere and being reflected by the terrestrial surface and clouds. Combining solar irradiance measurements within the same range of wavelengths with measurements of solar UV radiation it is possible to calculate both the atmospheric total ozone distribution and the vertical ozone profile. The SBUV instrument is carried abroad the satellite Nimbus-7 and flies in the Sun-synchronous, near polar orbit and allows for about 1300 observations per day (Varotsos et al., 1998).