REMOTE SENSING AND GIS APPLICATIONS IN LAKE STUDIES

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INTRODUCTION

Lakes and reservoirs are often referred to as standing waters and encompass a wide range of types and sizes. These range from ponds, gravel pits and slow moving canals to very large natural lakes. Lakes are large bodies of standing water, either formed naturally or man-made for amenity purposes. In this lecture note, application of remote sensing and GIS has been discussed.

Remote sensing refers to techniques used for collecting information about an object and its surroundings from a distance without physically contacting them. Normally, this gives rise to some form of imagery which is further processed and interpreted to produce useful data for application in agriculture, archaeology, forestry, geography, geology, planning and other fields. Information about the object concerned is obtained by a sensor system located on a satellite or aircraft, which receives electromagnetic radiation which has been either emitted by the object or has interacted with the object. Here we will consider the latter case, in which the source of radiation is not the object.

BASIC COMPONENTS OF REMOTE SENSING

The overall process of remote sensing can be broken down into five components. These are: 1) an energy source; 2) the interaction of this energy with particles in the atmosphere; 3) subsequent interaction of energy with the ground target; 4) energy recorded by a sensor as data; and 5) data displayed digitally for visual and numerical interpretation. Figure 1 illustrates the basic elements of airborne and satellite remote sensing systems.

- Energy source or illumination (A) which is a fundamental requirement for remote sensing system.
- Radiation and the atmosphere (B) - energy will come in contact and will interact with the atmosphere it passes through .The interaction may take place a second time as the energy travels from the target to the sensor.
- Interaction with the Target (C) - once the energy makes its way to the target through the atmosphere, it interacts with the target in a manner depending on the properties of both the target and the radiation.

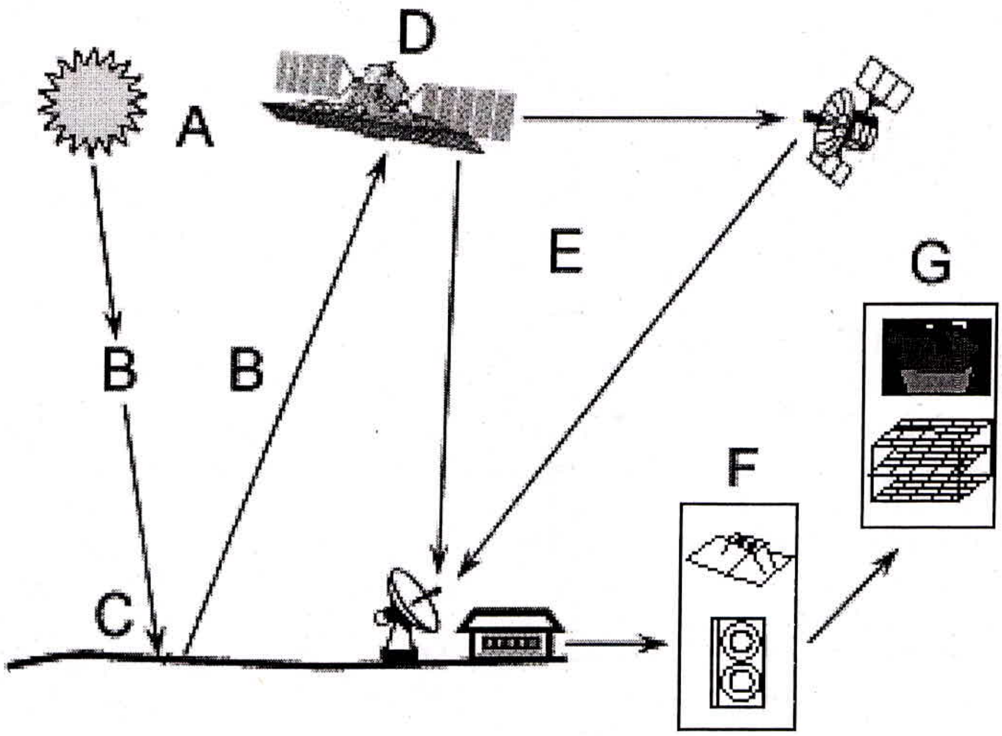

Fig. 1. Basic elements of airborne and satellite remote sensing system

- Recording of Energy by the Sensor (D) - after the energy has been scattered by or emitted from the target, a sensor (remote - not in contact with the target) collects and records the electromagnetic radiation.
- Transmission, Reception, and Processing (E) - the energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hard copy and/or digital) and recorded .
- Interpretation and Analysis (F) - the processed image is interpreted, visually and/or digitally, to extract usable information about the target
- Application (G) - the final element of the remote sensing process is achieved when we apply the information that has been extracted from the imagery about the target to better understand it, reveal some new information, or assist in solving a particular problem.

The electromagnetic radiation (EM) is the source of all signals collected by most remote sensing instruments. The source of this energy varies depending on the sensor characteristics. Most systems rely on the sun to generate all the EM energy needed to image terrestrial surfaces. These systems are called *passive sensors*. Other sensors generate their own energy, called *active sensors*, transmit that energy in a certain direction and records the portion reflected back by features within the signal path. Electromagnetic energy can be generated by changes in the energy levels of electrons, acceleration of electrical charges, decay of radioactive substances, and the thermal motion of atoms and molecules. Table 1 lists some representative applications for different spectral bands available from existing satellites.

Table 1 Remote Sensing Applications for different Spectral bands

Spectral band m	Applications
Blue (0.45 -0.50) Green (0.50- 0.60) Red (0.60- 0.70	Water penetration, land use, vegetation characteristics, sediment Green reflectance of healthy vegetation Vegetation discrimination because of red chlorophyll absorption
Panchromatic (0.50 -0.75) Reflective Infrared (0.75 -0.90)	Mapping, land use, stereo pairs Biomass, crop identification, soil-crop, land-water boundaries
Mid-infrared (1.5 -.1.75) Mid-infrared (2.0- 2.35)	Plant turgidity, droughts, clouds, snow-ice discrimination Geology, rock formations
Thermal infrared (10 - 12.5)	Relative temperature, thermal discharges, vegetation classification, moisture studies, thermal inertia
Microwave- Short wave (0.1- 5 cm)	Snow cover, depth, vegetation water content
Microwave-Long wave (5- 24 cm)	Melting snow, soil moisture, water-land boundaries, penetrate Vegetation.

REFLECTANCE CHARACTERISTICS OF DIFFERENT OBJECTS

Spectral Reflectance Curves

A surface feature's color can be characterized by the *percentage* of incoming EM energy (illumination) it reflects at each wavelength across the electromagnetic spectrum. This is its spectral reflectance curve or "spectral signature"; it is an unchanging property of the material. For example, a leaf may reflect 3% of incoming blue light, 10% of green light and 3% of red light. The amount of radiation it reflects depends on the amount and wavelength of incoming illumination, but the percents are constant. Unfortunately, remote sensing instruments do not record reflectance directly. Rather radiance, which is the *amount* (not the percent) of electromagnetic energy received in selected wavelength bands is recorded . A change in illumination, more or less intense sun for instance, will change the radiance. Spectral signatures are often represented as plots or graphs, with wavelength on the horizontal axis, and the reflectance on the vertical axis

Important Reflectance Curves and Critical Spectral Regions

While there are too many surface types to memorize all their spectral signatures, it is helpful to be familiar with the basic spectral characteristics of green vegetation, soil, and water. This in turn helps determine which regions of the spectrum are most important for distinguishing these surface types.

Spectral Reflectance of Green Vegetation

Reflectance of green vegetation is low in the visible portion of the spectrum owing to chlorophyll absorption, high in the near IR due to the cell structure of the plant, and lower again in the short-wave IR due to presence of water in the cells. Within the visible portion of the spectrum, there is a local reflectance peak in the green (0.55 μm) between the blue (0.45 μm) and red (0.68 μm) chlorophyll absorption valleys .

Spectral Reflectance of Soil

Soil reflectance typically increases with wavelength in the visible portion of the spectrum and then stays relatively constant in the near-IR and short-wave IR, with some local dips due to water absorption at 1.4 and 1.9 μm and due to clay absorption at 1.4 and 2.2 μm

Spectral Reflectance of Water

Spectral reflectance of clear water is low in all portions of the spectrum. Reflectance increases in the visible portion when materials are suspended in the water.

Reflectance characteristics of some of the features that are commonly in the analysis of environmental systems are shown in Fig 2.

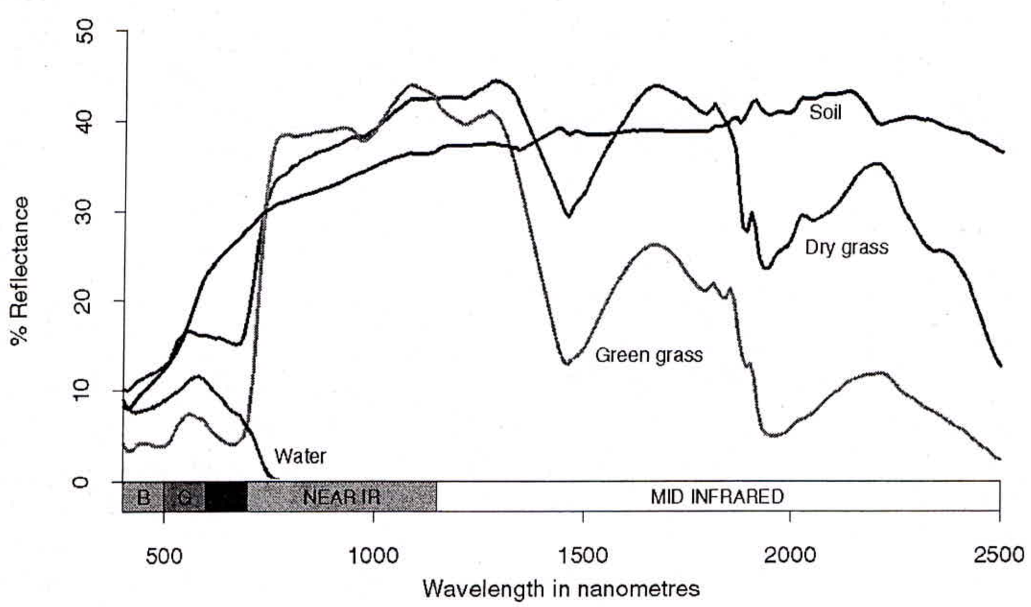

Figure 2. Spectral reflectance curves

RESOLUTIONS

Pixel size is very important factor in determining the size and types of features visible in an image. Images with large pixels can reveal landscape size features over a large area, but will not have enough fine detail to document smaller features. In the case of small lakes or lakes with a convoluted shoreline, large pixels can leave out many of the most interesting sections of the water body. On the other hand, while images with small pixels allow for the observation of small water body features, these images are often data dense and have smaller footprints. Images with smaller pixels could provide too much data to handle, or might not cover the entire water body when working with a larger lake system. Remotely sensed data can have four categories of resolution.

Spectral Resolution

This is the number and dimension of specific wavelength intervals in the EM spectrum to which a sensor is sensitive. There are many possible bands that can be used by a remote sensing system. Some are ideal for one set of applications, while others are good for a different set. Availability of spectral resolution depends up on sensor design.
The number, position and width of bands present in a sensor have an enormous influence on the applications for which a sensor can be used. While a few sensors have the ability to adjust bands on the fly, the vast majority of remote sensors have unmovable bands which are chosen based on the application for which the sensor was designed. For the measurement of land features, wide bands in the visible and infrared range provide sufficient information for many applications.

Spatial Resolution

The resolution of an image can be described as the closest that two objects can be together and still be reliably distinguished. The spatial resolution of images acquired by satellite sensor systems is usually expressed in meters. A 30-meter resolution means that two objects, 30 meters long or wide sitting side by side can be separated on the image. High resolution allows distinguishing relatively small objects or those that are closely spaced. In an imagery taken at 3-meter resolution, for example, cars can be distinguished from trucks, while in an imagery taken at 10-meter resolution; neither cars nor trucks can be identified. High spatial resolution implies imaging a small area. For an image of 1000 pixels square, at 20m resolution the area viewed is 20x20km, but at 1km resolution this increases to 1000x1000km (actually rather more, due to the variation in viewing angle over a large area). The latter is therefore suitable for large-scale studies.

Radiometric Resolution

Radiometric resolution or radiometric sensitivity refers to the number of digital levels used to express the data collected by the sensor. Quantization level, sensitivity of a sensor to differences in signal strength (e.g., number of bits, integer or floating point). In general, the greater the number of levels the greater the detail in the information. The number of levels is commonly expressed in terms of the number of binary digits (bits) needed to store the value of the maximum levels. For 2 levels the number of bits is 1, while for 4, 16, 64 and 256 levels the number of bits required is 2, 4, 6 and 8 respectively. Thus, "6-bit" data have 64 possible levels, represented by the integer values 0 to 63 inclusive.

Temporal Resolution

It shows how often the sensor records imagery of a particular area . Typical range of temporal resolution is 1 day to 24 days.

IMAGE INTERPRETATION

The main objective of image interpretation is to extract information about features displayed in an image. It is defined as the act of examining images for the purpose of identifying objects and finding their significance. The extraction of information depends on image analyst's experience, power of observation, imagination and patience. It also depends on his understanding of the basic principles of an image.

VISUAL INTERPRETATION

It is a traditional method for extracting information on various natural resources. There are certain fundamental photo elements or image characteristics seen on the image which aid in the visual interpretation of satellite imagery. Tone/colour; texture, shadow, shape, size, location and season etc. and their association are some of the basic image characteristics on which visual interpretation is based. Some of the shortcomings of the visual interpretation are:

(a) it is difficult to get consistent result from different interpreters
(b) it is difficult to achieve precise registration of multi-band and temporal images
(c) human can only detect the difference between 8-16 different shades of gray however the range of gray values recorded on the film is limited. Thus nowadays we go for digital image processing.

DIGITAL IMAGE PROCESSING

Any pictorial image can also be represented in digital form, so that the patterns of image brightness forms an array of numeric values which can be conveniently added, subtracted, multiplied, divided, and in general subjected to statistical manipulations that are difficult or impossible, if the image is available in pictorial form. Digital analysis encompasses a broad set of operations by which remotely sensed data are subjected to operations that yield information or enhanced data. It must be remembered that digital analyst is not totally free from human interactions. It requires significant inputs from the analyst while making decisions, thus providing information at faster rate, with high quality output, when compared with manual interpretations.

Image processing systems require various input/output devices, central processing unit (CPU), data storage devices and system consoles for man-machine interaction. Adequate image display facilities are important in the processing of an image.

The image processing software required in remote sensing applications can be broadly, grouped such as Data input routines, Pre-processing routines, Image display routines, Image enhancement and filtering routines, Classification routines, Image output routines.

An idealized sequence for digital analysis can be broken up into four specific groups;

(a) Pre-processing
(b) Enhancement,
(c) Georefenceing and Mosaic
(c) Analysis and Classification, and

USE OF REMOTE SENSING IN LAKE MANAGEMENT

Identification of lake area

The size of the lake or feature of the lake will play an enormous role in the selection of the appropriate sensor. For large lakes or large land areas, sensors designed for the open ocean with 1-1.1 km pixels (such as AVHRR and MODIS) will provide sufficient spatial resolution. For lakes too small for such large pixels, another option would be the medium resolution sensors. The pixels in these sensors (250-350 meters) are still too big for a many lakes, but they might prove useful in lakes where having 9-16 pixels for every 1 km pixel from the ocean sensors would produce useable data on water characteristics. Satellite sensors such as IRS LISSIII, ASTER, Landsat TM and ETM can provide fairly detailed land mapping and are useful in lakes down to ~4 hectares in size. Fine resolution sensors such as IRS LISSIV, SPOT, IKONOS and QuickBird would provide very fine details of both land and water bodies.

For lakes identification from the satellite images, the image should be cloud free. The detection of lakes using multi spectral imagery involves discriminating between water and other surface types. Delineating surface water can be achieved using the spectral reflectance differences. Water strongly absorbs in the near- and middle-infrared wavelengths (0.8–2.5μm). Vegetation and soil, in contrast, have higher reflectance in the near- and middle-infrared wavelengths; hence water bodies appear dark compared to their surroundings when using these wavelengths. When applying basic techniques of multi spectral classification similar to those used for the normalized difference vegetation index, NDVI, a normalized difference water index (NDWI) for lake detection can be used. Applying the idea of two spectral channels with maximum reflectance difference for an object (i.e., water), a blue channel (maximum reflectance of water) and a near-infrared (NIR) channel (minimum reflectance of water) were chosen.

$$NDWI = \frac{\text{Green Band} - \text{NIR Band}}{\text{Green Band} - \text{NIR Band}}$$

The area of the lake was calculated using the digital techniques by counting the number of pixels falling inside the water body polygon.

Water Quality

Water quality is the process to determine the chemical, physical and biological characteristics of water bodies and identifying the source of any possible pollution or contamination which might cause degradation of the water quality. These water quality indicators can be categorized as: (i) Biological: bacteria, algae, (ii) Physical: temperature, turbidity and clarity, color, salinity, suspended solids, dissolved solids, (iii) Chemical: pH, dissolved oxygen, biological oxygen demand, nutrients (including nitrogen and phosphorus), organic and inorganic compounds (including toxicants) and (iv) Aesthetic: odors, taints, color, and floating matter. Remote sensing of monitoring water quality has been started in the early 1970's. Ritchie *et al.*, (1974) were developed an early empirical approach to estimates suspended sediments general equation as follows:

$$Y=A+BX \text{ or } Y=ABX$$

where, Y is the remote sensing measurement (i.e., radiance, reflectance, energy) and X is the water quality parameter of interest (i.e., suspended sediment, turbidity). A and B are empirically derived factors that this value are gained from statistical relationship which determined from spectral reflectance value and between the *in* situ water quality parameter. From the spectral reflectance it can give the information about the band or wavelengths are suitable for that water quality parameter. This equation later on was applied by other researcher to estimates water quality parameter. In future, if the empirical equation was successful developed for each water quality parameter, the equation can be used to estimates the same water quality parameter on area under investigation.

Suspended matter comprises organic and inorganic matter. Suspended matter plays an important role in water quality management since it is related to total primary production and fluxes of heavy metals and micro-pollutants. Suspended matters are the most common pollutants in surface water. Some researcher has discussed the relationship between suspended sediment and reflectance. The suspended sediments increases the radiance from surface water in visible and near infrared ranged of the electromagnetic spectrum. In situ and laboratory measurement has shown that the surface water radiance is affected by sediments type, texture, color, sensor view and sun angles, and water depth (Ritchie and Frank, 1998). Remote sensing techniques can be used to estimate and map the concentrations of suspended matter in inland water, providing both spatial and temporal information. Remote sensing studies of suspended matter have been using from various of satellite platform such as Landsat, SPOT, IRS.
Water turbidity is an expression of the optical properties of water, which cause the light to be scattered and absorbed rather than transmitted in straight lines. It is therefore commonly regarded as the opposite of clarity. As water turbidity is mainly caused by the presence of suspended matter, turbidity measurement has often been used to calculate fluvial suspended sediment concentrations

Advantages of Remote Sensing in Monitoring Water Quality

One major advantage of remote sensing observations over traditional measurements for water quality monitoring provides both spatial and temporal information of surface water characteristics. With present advanced satellite sensors, a large number of water quality information about chlorophyll-a, suspended sediment, yellow substance, turbidity, Secchi disk depth, wave height, color index and surface water temperature can be observed on a regular basis. Besides, remote Sensing technique has been widely used for water quality studies in coastal and inland lakes. Remotely sensed data have the potential to provide knowledge of broad scale changes, the link between offshore and near-shore waters, and the ability to obtain a long-term, near-daily view of the region of interest indicating seasonal and inter annual variability. Other than that, by advanced technology from remote sensing it is a cheaper and repetitive quantitative technique for measuring water quality that will allow adequate management. It was various previous literatures that indicate success in using remote sensing to assess water quality such as in.

Compare to limnological studies, *in situ* measurements is often restricted to selected sampling points. But by Remote sensing data it provides the synoptic view of the water body, obtain to measures the characteristics of an area rather than a point, can integrate several characteristics with one composites measurements and ability to improve models with continuous or frequent feedback from satellite measurements. An intensive *in situ* sampling programmed can validate the remotely sensed products as well as provide an assessment of factors not able to be observed from space such as changing biota, substrate and chemical makeup. An improved understanding of these factors, and how they relate to remotely sensed products may enable development of remotely sensed environmental indicators, able to be monitored using space based measurements, but related to characteristics of the environment not directly observable from space.

USE OF GEOGRAPHIC INFORMATION SYSTEM

Geographic information system (GIS) can be considered as a database management system that can be used for entering, storing, retrieving, trans-forming, measuring and combining spatial data. The system integrated with a series of routines that allow sophisticated spatial analysis and display. The data must have been digitized and registerd to common coordinate system.

Main Functions of GIS

♦ All GIS operations can, in principle, be done manually, but many tasks are so time consuming that they can be manually performed only for very small research areas. By using computers and their graphics facilities and a GIS software, the laborious tasks can be performed with ease. The early concepts of map handling by a computer had a serious drawback in that they could not handle the tabular or attribute data in conjunction with spatial features. This led to the development of additional methods and techniques where the spatial and attribute data both could be handled and integrated so that the outputs are more meaningful for planners and decision-makers. The upcoming of this technology has enhanced our capability not only of map handling but also of map manipulation and analysis. Therefore, using a GIS:

♦ Users can interrogate geographical features displayed on a computer map and retrieve associated attribute information for display or further analysis.

♦ Maps can be constructed by querying or analysing attribute data.

♦ New sets of information can be generated by performing spatial operations (such as polygon overlay) on the integrated database.

♦ Different items of attribute data can be associated with one another through a shared location code.

Before any spatial analysis or modelling operations can be carried out in a GIS, it is necessary to input the requisite data. Data input is the procedure of encoding data into computer-readable form and writing the data to the GIS database. The data to be entered in a GIS are of two types - spatial data and associated non-spatial attribute data. The spatial data represent the geographic location of features. Points, lines and areas are used to represent geographic features like a street, a lake or a forest land. These data will normally be obtained from one or more of the following sources:

- Existing maps
- Aerial photographs
- Satellite imageries
- Existing digital data
- Other GIS data bases

Remote sensing is an important source of data for GIS analysis and conversely, GIS data can serve as an important aid in image analysis. The need of integration of GIS and remote sensing is thus inevitable, and is rapidly emerging because of the complementry role played by these technologies.

Bathymetric information on lakes has important value in hydrology. Besides water level-volume–lake area or stage curve relationships, multi temporal comparison between bathymetric is an indicator for environmental changes like lake sedimentation. Monitoring lake bathymetry has becomes attractive using recent advances in Global Positioning System and GIS software analysis tools. Estimates of lake volume are necessary for calculating residence time and modeling pollutants. Modern GIS methods for calculating lake volume improve on more dated technologies (e.g., planimeters) and do not require potentially inaccurate assumptions (e.g., volume of a frustum of a cone), but most GIS methods do require detailed bathymetric data, which may be unavailable. GIS technology cannot correct for a lack of data; however, it can facilitate development of methods that better use the relatively simple and more widely available measurements of lake shape and maximum depth.

Mapping water quality in lake waters has been performed in the past mainly by producing contour maps, which can be difficult to read when there is a lot of information that the map contains. However, a graphical image produced by a GIS will provide the user an easier visual inspection of the water quality conditions of the lake for the desired time period.

CONCLUDING REMARKS

Remote sensing and GIS techniques are the effectiveness, cheaper and valuable tools in monitoring water quality parameter in lake area compared to *in situ* where measurement is restricted to selected sampling points. From the example of the past research by remote sensing and GIS techniques it was concluded that water quality parameter can be produced in the form of map using the algorithm or models by various platforms of satellite imagery with various resolutions. Newly developed hyperspectral imaging, which can simultaneously record up to 200+ spectral channels, is a much more powerful probe. Hyperspectral imaging has greater potential because of its simultaneous collection of images covering many narrow, contiguous wavelength bands that allow various aspects of water quality to be measured and monitored. Each water quality parameter such as suspended matter, phytoplankton concentration, turbidity, and dissolved organic matter has their own estimation reflectance within the range of 400-850 μm. The methodology developed using GIS can be be used for rapid bathymetric survey and map generation.

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