

Introduction to Remote Sensing and GIS

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Surveying and mapping is basic to effective water management. In the conventional engineering studies, the traditional inputs are topographical maps, aerial photographs and ground survey. Topographical maps depicting current status of the region under study are seldom available because of longer revision cycles. Aerial photography is expensive besides being procedurally cumbersome. Ground surveys are too costly, time consuming and laborious. It is here that remote sensing and Geographic Information System (GIS) help in creating an appropriate information base for efficient management of the water resources. The synoptic view provided by satellite remote sensing and the analysis capability provided by GIS offer a technologically appropriate method for studying various features related to land and water resources. It is worth mentioning here that remote sensing cannot entirely do away with conventional surveying, but it can limit the ground surveys.

Remote sensing is a tool permitting accurate and real time evaluation, continuous monitoring or surveillance and forecast of inland water resources. Remote sensing systems are used to observe the earth's surface from different platforms such as satellites and aircraft, and make it possible to collect and analyse information about resources and environment over large areas. Remote sensors record electromagnetic energy reflected or emitted from earth's surface. Different kinds of objects or features such as soils, vegetation and water reflect and emit energy differently. This characteristic makes it possible to measure, map and monitor these objects and features using satellite or aircraft borne remote sensing systems. Satellite images provide a low cost and potentially rapid means to monitor and map the different land cover features. One of the greatest advantages of using remote sensing data for hydrological monitoring and modeling is its capability to generate information in spatial and temporal domain, which is important in water management studies.

For many water related studies, remote-sensing data alone are not sufficient; they have to be merged with data from other sources. Hence a multitude of spatially related (i.e. climatic and geographic) data concerning rainfall, evaporation, vegetation, geomorphology and soils has to be considered. In addition, information is also required such as locations and type of tube wells, rain and river gauges etc. Thus the fast storage, retrieval, displays and updating of map contents are important functions. A system that can store the data, select and classify the stations and perform mathematical and sorting operations is called a database and information can be extracted from it for a given purpose. If this information can also be displayed in the form of maps, we can speak of geographic information. So this complete set of information forms the GIS. GIS is an effective tool for storing, managing, and displaying spatial data often encountered in hydrology and water resources management related studies. GIS technology integrates common database operations, such as queries and statistical analysis, with the unique visualization and geographic analysis benefits offered by maps and spatial databases.

Basic components of remote sensing

The overall process of remote sensing can be broken down into five components. These components are: 1) an energy source; 2) the interaction of this energy with particles in the atmosphere; 3) subsequent interaction 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.

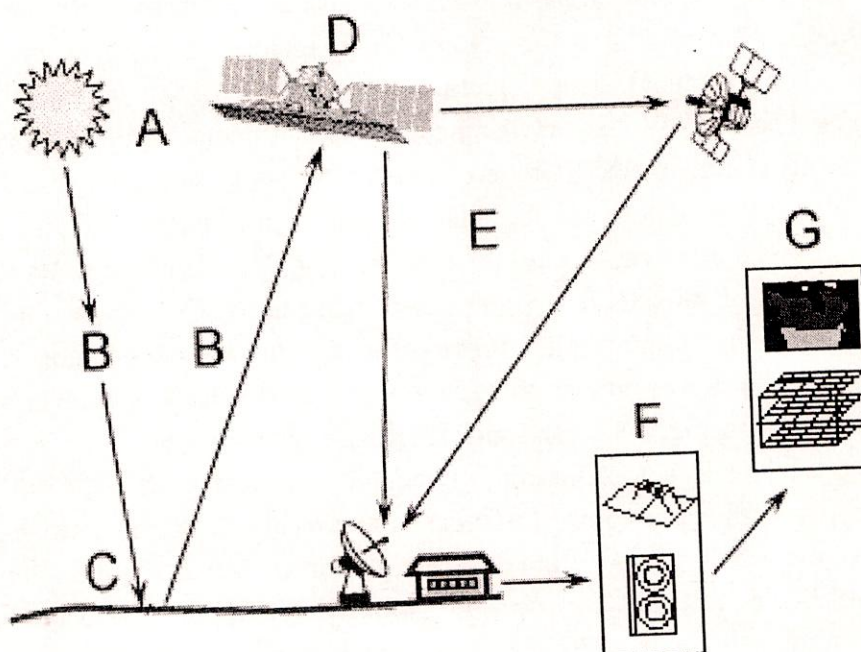


Figure 1: Basic elements of airborne and satellite remote sensing systems.

- Energy Source or Illumination (A) - fundamental requirement for remote sensing system.
- Radiation and the Atmosphere (B) - energy will come in contact with and interact with the atmosphere it passes through - 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.
- Recording of Energy by the Sensor (D) - after the energy has been scattered by, or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record 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).
- Interpretation and Analysis (F) - the processed image is interpreted, visually and/or digitally, to extract information about the target.
- Application (G) - the final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in

order to better understand it, reveal some new information, or assist in solving a particular problem.

REFLECTANCE CHARACTERISTICS OF DIFFERENT OBJECTS

Spectral Reflectance Curves

A surface feature's color can be characterized by the *percentage* of incoming electromagnetic energy (illumination) it reflects at each wavelength across the electromagnetic spectrum. This is its spectral reflectance curve (Fig. 2) or "spectral signature"; it is an unchanging property of the material. For example, an object such as a leaf may reflect 3% of incoming blue light, 10% of green light and 3% of red light. The amount of light 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. 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 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. Water absorption is a phenomenon in the transmission of electromagnetic radiation through a medium containing water molecules. Water molecules are excited by radiation at certain wavelengths and tend to selectively absorb portions of the spectrum while allowing the balance of the spectrum to be transmitted with minimal effect.

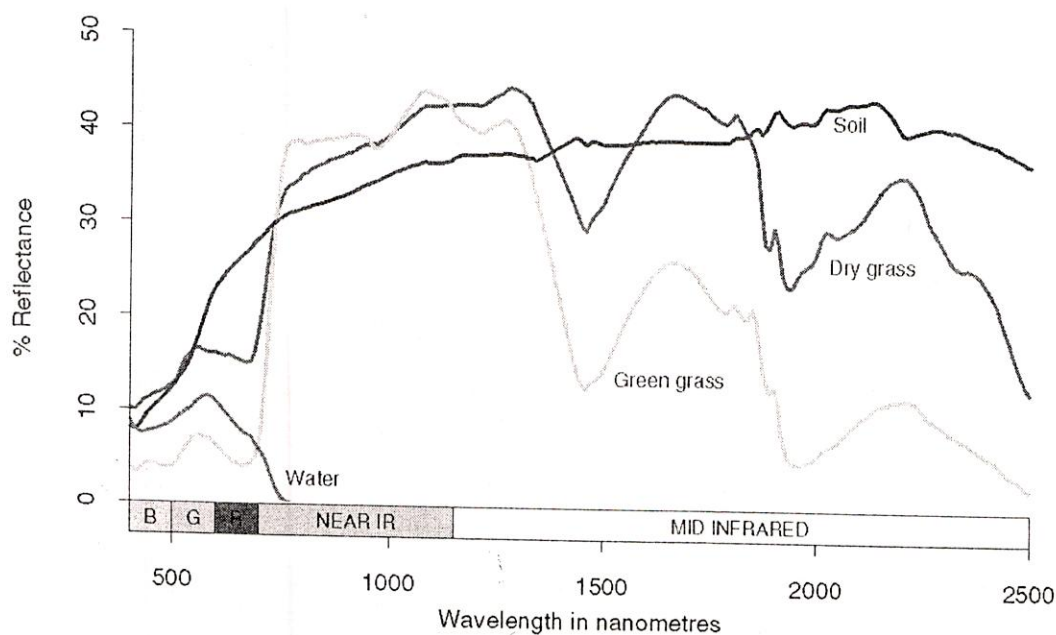


Fig. 2: Spectral reflectance curve of some earth features.

INTERPRETATION OF REMOTE SENSING DATA

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. The synoptic view provided by satellite images is of great importance in water resources in detecting large features and understanding their inter-relationships.

Digital Data

In a most generalized way, a digital image is an array of numbers depicting spatial distribution of a certain field parameters (such as reflectivity of EM radiation, emissivity, temperature or some geophysical or topographical elevation). Digital image consists of discrete picture elements called pixels. Associated with each pixel is a number represented as DN (Digital Number) that depicts the average radiance of relatively small area within a scene. The range of DN values being normally 0 to 255. The size of this area effects the reproduction of details within the scene. As the pixel size is reduced more scene detail is preserved in digital representation.

Remote sensing images are recorded in digital forms and then processed by the computers to produce images for interpretation purposes. Images are available in two forms - photographic film form and digital form. Variations in the scene characteristics are represented as variations in brightness on photographic films. A particular part of scene reflecting more energy will appear bright while a different part of the same scene that reflecting less energy will appear black. Digital image consists of discrete picture elements called pixels. Associated with each pixel is a number represented as DN (Digital Number) that depicts the average radiance of relatively small area within a scene. The size of this area effects the reproduction of details within the scene. As the pixel size is reduced more scene detail is preserved in digital representation.

IMAGE INTERPRETATION

Analysis of remotely sensed data is done using various image processing techniques and methods that includes:

- Analog image processing
- Digital image processing.

DIGITAL IMAGE PROCESSING

Image processing in the context of remote sensing refers to the management of digital images, usually satellite or digital aerial photographs. Image processing includes the display, analysis, and manipulation of digital image computer files. The derived product is typically an enhanced image or a map with accompanying statistics and metadata. Digital Image Processing is a collection of techniques for the manipulation of digital images by computers. The raw data received from the imaging sensors on the satellite platforms contains flaws and deficiencies. To overcome these flaws and deficiencies in order to get the originality of the

data, it needs to undergo several steps of processing. This will vary from image to image depending on the type of image format, initial condition of the image and the information of interest and the composition of the image scene. Digital Image Processing undergoes three general steps:

- Pre-processing
- Display and enhancement
- Information extraction

When remotely sensed data is received from the imaging sensors on the satellite platforms it contains flaws and deficiencies. Pre-processing refers to those operations that are preliminary to the main analysis. Preprocessing includes a wide range of operations from the very simple to extremes of abstractness and complexity. These categorized as follow:

1. Feature Extraction
2. Radiometric Corrections
3. Geometric Corrections
4. Atmospheric Correction

The techniques involved in removal of unwanted and distracting elements such as image/system noise, atmospheric interference and sensor motion from an image data occurred due to limitations in the sensing of signal digitization, or data recording or transmission process. Removal of these effects from the digital data are said to be "restored" to their correct or original condition, although we can, of course never know what are the correct values might be and must always remember that attempts to correct data what may themselves introduce errors. Thus image restoration includes the efforts to correct for both radiometric and geometric errors.

GEOGRAPHIC INFORMATION SYSTEM (GIS)

The GIS is derived from multiple sources of data with different levels of accuracies. While a single piece of data can be assigned an accuracy value, information derived from multiple sources of inaccurate data can also be assigned a level of accuracy. In any pictorial representation of data the uncertainty can be brought in as one of the dimensions to guide the final decision-making. Any decision today has to depend on a variety of factors, which are available in an information system like GIS.

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

DATA ENTRY

Data to be imported into a GIS can exist in a number of different models e.g. tables of numeric data, alphabetic text, paper plans, photographs, digital files. Obviously, of these models of data listed above, the digital data (whether on a floppy disk, hard disk, CD ROM, network server etc.) may simply be able to be loaded into the GIS as you would do with any other computer application like word-processing etc. Since computers can only work with digital information, any non-digital (called analogue) data needs to be converted to digital form before it can be used in a GIS. Spatial information, from printed or drawn maps or plans, must be digitised before it is available for use; photographs, etc., must be scanned to obtain a digital representation.

There are five types of data entry systems commonly used in a GIS: keyboard entry, coordinate geometry, manual digitizing, scanning, and the input of existing digital files. Keyboard entry, as its name implies, involves manually entering the data at a computer terminal. Attribute data are commonly input by keyboard. Manual digitizing is the most widely used method for entering spatial data from maps. The map is mounted on a digitizing table and a hand held device, termed a puck or cursor, is used to trace each map feature. The position of the cursor is accurately measured by the device to generate the coordinate data in digital form.

Scanning, also termed scan digitizing, is a more automated method for entering map data. A raster digital image of the map is produced after which additional computer processing is done to improve the quality of the image and to convert the raster data to vector format. Operator-assisted editing and checking is then done to generate the final GIS-compatible data file.

KEYBOARD ENTRY AND COORDINATE GEOMETRY PROCEDURES

Most attribute data are entered by keyboard. In many cases these data can be obtained in digital form from an existing data base into which they were keyboard entered. Field observations can be recorded in digital form by keyboard entry of the data in the field using small hand-held computers. The data files are then periodically downloaded to another computer or copied onto diskette for storage.

Keyboard entry can be used during manual digitizing to enter the attribute information. However, this is usually more efficiently handled as a separate operation in which the attributes are entered with a code to indicate the spatial element (such as the line or polygon feature) that they describe. The attribute file is subsequently linked to the spatial data.

MANUAL DIGITIZING

Where spatial information is to be digitised, choice of digitising technique involves not only consideration of the form and format of the data but it is also necessary to consider what the data is to be used for. For example, if distances along roads are to be measured then spherical coordinates (degrees of latitude and longitude) are not too helpful. Also, the size of

the area will determine whether curvature of the Earth has to be taken into account and hence the type of map projection used.

In manual digitizing the map is affixed to a digitizing table and a pointing device is used to trace the map features. Digitizing tables can be as large as 1 m x 1.5m or more. A smaller device, termed a digitizing tablet (usually equipped with a mouse instead of the more precise cursor) is commonly used as a device to operate the GIS. The digitizing table electronically encodes the position of the pointing device with a precision of fractions of a millimetre. The most common table digitizer uses a fine grid of wires embedded in the table. The cursor normally has a crosshair for precise positioning and 16 or more control buttons that are used to operate the data entry software and to enter attribute data. As the map elements are traced, the coordinate data generated from the digitizing table are either processed immediately by the GIS or are stored for later processing. The digitizing operation itself requires little computing power and so can be done off-line, i.e., not using the full GIS.

The efficiency of digitizing depends on the quality of the digitizing software and the skill of the operator. The process of tracing lines is time-consuming and error prone. The software can provide aids that substantially reduce the effort of detecting and correcting errors. Attribute data may be entered during the digitizing process, but usually only an identification number is coded. The attribute information referenced to the same identification numbers are then entered separately. If the attribute data are already in GIS-compatible files, they may be entered directly.

Manual digitizing is a tedious job. Operator fatigue can seriously degrade data quality. Work scheduling should limit the hours per day that an individual spends digitizing and suitable quality assurance procedures should be used to ensure that the digitized data and associated attribute data satisfy the required accuracy standards. A commonly used quality check is to produce a verification plot of the digitized data that is visually compared with the map from which the data were originally digitized.

SCANNING

Scanning (or scan digitizing) provides a faster means of data entry than manual digitizing. In scanning, a digital image of the map is produced by moving an electronic detector across the map surface. Two scanner designs are commonly used. In a flat-bed scanner the map is placed on a flat scanning stage over which the detector is moved in both X and y directions. In a drum-scanner, the map is mounted on a cylindrical drum. The detector is moved horizontally across the drum as it rotates. The sensor motion across the drum provides the movement in the X direction. The drum rotation provides the movement in the y direction.

The output from the scanner is a digital image. The fineness of detail captured by the scanner depends on the size of the map area viewed by the detector, termed the spot size. Spot sizes on the order of 20 microns (.02 mm) are commonly used. Scanners can record colour information by scanning the same document three times using red, green and blue filters. Usually only a black-and-white image is produced. The raster image is computer processed to improve the image quality and is then edited and checked by an operator. If the data are required in vector format, additional raster- to-vector conversion processing is done. During the editing procedure or after conversion to vector format, each spatial element is tagged and

assigned an identification number. The attribute data are linked to the spatial data by means of these identification numbers.

REGISTRATION

Image data commonly need to be rectified to a standard projection and datum. Registration or rectification is a procedure that distorts the grid of image pixels onto a known projection and datum. The goal in rectification is to create a faithful representation of the scene in terms of position and radiance. Rectification is performed when the data are unprojected, need to be re projected, or when geometric corrections are necessary. If the analysis does not require the data to be compared or overlain onto other data, corrections and projections may not be necessary.

There are two commonly used rectification methods for projecting data. Image data can be rectified by registering the data to another image that has been projected or by assigning coordinates to the unprojected image from a paper or digital map.

Image to Map Rectification. Unprojected images can be warped into projections by creating a mathematical relationship between select features on an image and the same feature on a map. The mathematical relationship is then applied to all remaining pixels, which warps the image into a projection.

Ground Control Points (GCPs). The procedure requires the use of prominent features that exist on both the map and the image. These features are commonly referred to as ground control points or GCPs. GCPs are well-defined features such as sharp bends in a river or intersections in roads or airports. The minimum number of GCPs necessary to calculate the transformation depends upon the order of the transformation. The order of transformation can be set within the software as 1st, 2nd, or 3rd order polynomial transformation. The equation identifies the number of GCPs required to calculate the transformation. If the minimum number is not met, an error message should inform the user to select additional points. Using more than the minimum number of GCPs is recommended.

$$(t + 1)(t + 2) = \text{minimum number of GCPs } 5-12$$

Where t = order of transformation (1st, 2nd, or 3rd).

To begin the procedure, locate and record the co-ordinate position of 10 to 12 features found on the map and in the image. Bringing a digital map into the image processing software will simplify co-ordinate determination with the use of a co-ordinate value tool. When using a paper map, measure feature positions as accurately as possible, and note the map co-ordinate system used. The type of co-ordinate system used must be entered into the software; this will be the projection that will be applied to the image. Once projected, the image can be easily projected into a different map projection.

After locating a sufficient number of features (and GCPs) on the map, find the same feature on the image and assign the co-ordinate value to that pixel. Zooming in to choose the precise location (pixel) will lower the error. When selecting GCPs, it is best to choose points from across the image, balancing the distribution as much as possible; this will increase the positional accuracy. Once the GCP pixels have been selected and given a co-ordinate value, the software will interpolate and transform the remaining pixels into position.

Positional Error. Most software programs generate a least squares or “Root Mean Square” (RMS) estimation of the positional accuracy of the mathematical transformation. The RMS estimates the magnitude transformation. The estimate will not be calculated until three or four GCPs have been entered. Initial estimates will be high, and these should decrease as more GCPs are added to the image. A root mean square below 1.0 is a reasonable level of accuracy. If the RMS is higher than 1.0, simply reposition GCPs with high individual errors or delete them and reselect new GCPs. With an error less than 1.0 the image is ready to be warped to the projection and saved.

Re-sampling Methods The location of output pixels derived from the ground control points (GCPs) are used to establish the geometry of the output image and its relationship to the input image. Difference between actual GCP location and their position in the image are used to determine the geometric transformation required to restore the image. This transformation can be done by different resampling methods where original pixels are resampled to match the geometric coordinates. Each resampling method employs a different strategy to estimate values at output grid for given known values for the input grid.

Nearest Neighbor The simplest strategy is simply to assign each corrected pixel, the value from the nearest uncorrected pixel. This approach has the advantages of simplicity and the ability to preserve original values in the altered scene, but it may create noticeable errors, which may be severe in linear features where the realignment of pixels is obvious.

Bilinear Interpolation The strategy for the calculation of each output pixel value is based on a weighted average of the four nearest input pixels. The output image gives a natural look because each output value is based on several input values. Some changes occur when bilinear interpolation creates new pixel value.

CAPABILITIES OF GIS

GIS provides a rich and flexible medium for visualizing and interacting with geographic data. A GIS includes a variety of functions for portraying attribute distributions and transforming spatial objects. You can also interact with a GIS to turn raw data into information useful for answering spatial and temporal questions. Through spatial analysis you can interact with a GIS to answer questions, support decisions, and reveal patterns. Spatial analysis is in many ways the crux of a GIS, because it includes all of the transformations, manipulations, and methods that can be applied to geographic data to turn them into useful information. While methods of spatial analysis can be very sophisticated, they can also be very simple.

The power of GIS lies in its ability to analyse spatial and attribute data together. The large range of analysis procedures can be divided into four categories:

- i) Retrieval, reclassification and measurement,
- ii) Overlay,
- iii) Distance and connectivity,
- iv) Neighbourhood

Retrieval, Reclassification and Measurement Operation:

In these functions retrieval of both spatial and attribute data are made and only attribute data are modified. New spatial elements are not created.

Retrieval operations:

Queries and reasoning are the most basic of analysis operations, in which the GIS is used to answer simple questions posed by the user. No changes occur in the database and no new data are produced. A GIS can respond to queries by presenting data in appropriate views and allowing the user to interact with each view. It is often useful to be able to display two or more views at once and to link them together. Linking views is one important technique of exploratory spatial data analysis. A user can interact with a map view to identify objects and query their attributes, to search for objects meeting specified criteria, or to find the coordinates of objects. When objects are selected in the table, they are automatically highlighted in the map view, and vice versa. The table view can be used to answer simple queries about objects and their attributes.

Retrieval operation includes the retrieval of data using:

- Geometric Classifications
 - Symbolic Specifications
 - A name or code of an attribute
 - Conditional and logical statement
- Retrieval operations on the spatial and attribute data involve the selective search and manipulation, and output of data without the need to modify the geographic location of features or to create new special entities. Retrieval operations include:
 - Retrieval of data using geometric classification. Specifying the spatial domain of a point, line or area, retrieve all spatial entities and nonspatial attributes contained in the entire or in position of that spatial domain.
 - Retrieval of data using symbolic specifications.
 - Retrieve data using a name or code of an attribute. Retrieve using a name or code of an attribute. Example, retrieve effective depth and dominant texture of a given soil.
 - Retrieval of data using conditional and logical statements. Retrieve data that satisfy alphanumeric conditions using logical expressions. Example retrieves all soil series with a pH range of 6.0 to 7.5 and silty clay texture.

Reclassification Procedures:

This procedure involves the operations that reassign thematic values to the categories of an existing map as a function of the initial value, the position, size or shape of the spatial configuration associated with each category, for instance a soil map reclassified into a permeability map. In a raster based GIS, numerical values are often used to indicate classes. A cell might be assigned value to indicate a class. For example a cell might be assigned the value 1 to indicate an agriculture land, 2 for forest land, and so on. Classification is done using single data layer as well as with multiple data layers as part of an overlay operation.

Measurement Functions:

Every GIS provides some measurement functions. The measurement of spatial data involves the calculation of distances, lengths of lines, area and perimeter of polygons. The measurements involving points include distances from a point to a other point, lines or a

polygon enumeration of total number as well as the enumeration of points falling within polygon. Many tasks require measurement from maps measurement of distance between two points measurement of area, e.g. the area of a parcel of land. Such measurements are tedious and inaccurate if made by hand measurement.

Uncertainty in the measurement of geographic phenomena

Error occurs in physical measurement of objects, in the recording of socioeconomic attributes, and in digital data capture. This error creates further uncertainty about the true nature of spatial objects.

Physical measurement error

Instruments and procedures used to make physical measurements are not perfectly accurate. For example, a survey of Mount Everest might find its height to be 8,850 meters, with an accuracy of plus or minus 5 meters. In addition, the earth is not a perfectly stable platform from which to make measurements.

Digitizing error

A great deal of spatial data has been digitized from paper maps. Digitizing, or the electronic tracing of paper maps, is prone to human error. Lines may be drawn too far, not far enough, or missed entirely. Errors caused by digitizing mistakes can be partially, but not completely, fixed by software.

Overlay Operations:

Overlaying of maps results in the creation of a map where the values assigned to every location on that map are computed as a function of independent values associated with that location on two or more existing maps. Overlaying operation creates a new data set containing new polygons formed from the intersection of the boundary of the two or more sets of separate polygon layers. Arithmetical and logical overlay operations are common in all GIS software packages.

Arithmetical overlay includes operations such as addition, subtraction, division and multiplication of each value in a data layer by the value in the corresponding location in the second data layer. Logical overlay involves the selection of an area where a set of conditions are satisfied.

Neighbourhood operations:

Neighbourhood operations involve the creation of new data based on the consideration of 'roving window' of neighbourhood points about selected target locations. They evaluate characteristics of an area surrounding a specified target location. In all neighbourhood operations it is necessary to indicate one or more target locations, the neighbourhood considered around each target and the type of function to be executed on the attributes within the neighbourhood. The typical neighbourhood operations in most GIS are search function, topographic function and interpolation.

Interpolation:

Interpolation is the procedure of predicting unknown values using the known values at neighbouring locations. The neighbouring points may be regularly or irregularly spaced. Interpolation programs employ a range of methods to predict unknown values including polynomial regression, Fourier series, moving averages, and krigging, etc.

SUMMARY

Remote sensing is now being widely regarded as a layer in the GIS. Although remote sensing is a specialized technique, it is now being accepted as a basic survey methodology and as a means of providing data for a resource database. The future progress in the hydrological sciences will depend upon the availability of adequate data for model development and validation. Remote sensing can and should play a pivotal role in this progress. The data banks should provide digitized maps and their spatial data compatible with various systems. Such data availability could significantly speed up the analysis.

GIS offers many capabilities for displaying data at differing scales and based on various attributes. Spatial analysis is also a source of information from a GIS and is defined by any set of methods whose results change when the locations of the objects being analyzed change. Spatial analyses are queries and reasoning, measurements, transformations, descriptive summaries etc. Uncertainty enters GIS at every stage. It occurs in the conception or definition of spatial objects. Uncertainty occurs in the measurement of data. It is caused by imperfect instruments, errors in the conversion of non-digital data to digital form (digitizing), and the combination of data sets with different characteristics (different datum, different scales, different data processing histories). Uncertainty occurs in the structural representation of data as either vectors or raster. In the vector data structure, distortion is caused by the common practice of aggregating point data to polygons. In the raster structure, it is caused by data generalization.
