REMOTE SENSING AND GIS

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Introduction

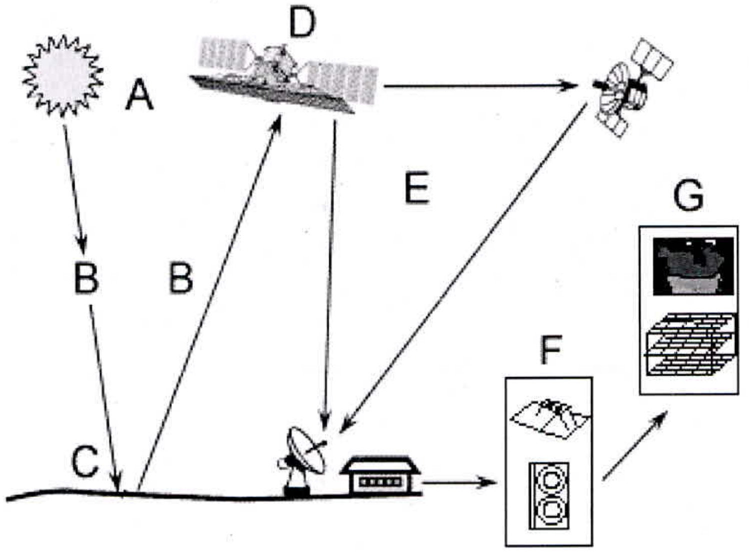
Conventional models require considerable hydrological, meteorological and spatial data. Collection of land use, soil and other spatial data is expensive, time consuming and a difficult process. Remote Sensing (RS) and Geographical Information System (GIS) play a rapidly increasing role in collection and analysis of such spatial data. The role of remote sensing in runoff calculation is generally to provide a source of input data or as an aid for estimating equation coefficients and model parameters. Experience has shown that satellite data can be interpreted to derive thematic information on land use, soil, vegetation, drainage, etc which, combined with conventionally measured climatic parameters (precipitation, temperature etc) and topographic parameters height, contour, slope, provide the necessary inputs to the hydrological models. The information extracted from remote sensing and other sources can be stored as a geo-referenced database in GIS. The system provides efficient tools for data input into database, retrieval of selected data items for further processing. The use of RS and GIS is applicable in rainfall runoff, soil erosion, snowmelt runoff and groundwater modelling. In this chapter basics of remote sensing and GIS have been covered which is followed by role of these techniques in modeling.

Remote Sensing Techniques

Remote sensing is a technology used for obtaining information about a target through the analysis of data acquired from the target at a distance. It is composed of three parts, the targets - objects or phenomena in an area; the data acquisition - through certain instruments; and the data analysis - again by some devices. Remote sensing data acquisition can be conducted on such platforms as aircraft, satellites, balloons, rockets, space shuttles, etc. Inside or on-board these platforms, we use sensors to collect data. Sensors include aerial photographic cameras and non-photographic instruments, such as radiometers, electro-optical scanners, radar systems, etc.

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.



- 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 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.

Strong water vapor absorption bands occur at wavelengths around 2500, 1950 and 1450 nanometers (nm), with weaker absorption around 1200 and 970 nm, and three additional sets of water-vapor absorption lines near 930, 820, and 730 nm, all in the infrared spectrum. Water has a complex absorption spectrum — the 2007 HITRAN spectroscopy database update lists more than 64,000 spectral lines corresponding to significant transitions of water vapor ranging from the microwave region to the visible spectrum

Resolutions

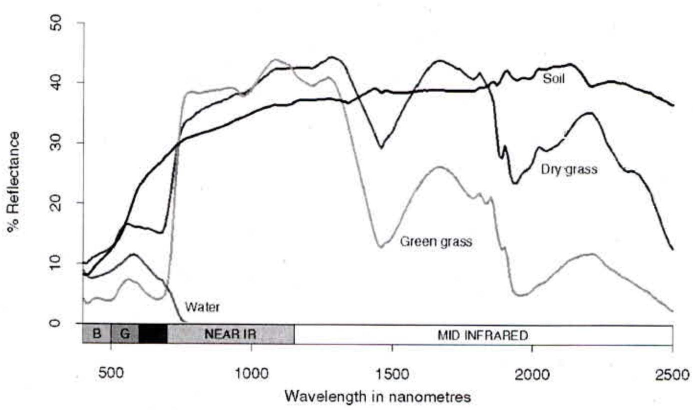
The four resolutions of remotely sensed data

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.

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 imagery taken at 3-meter resolution, for example, cars can be distinguished from trucks, while in 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

Quantization level, sensitivity of a sensor to differences in signal strength (e.g., number of bits, integer or floating point)

Temporal Resolution

How often the sensor records imagery of a particular area

Remote Sensing Platforms

Platform is a stage to mount the camera or sensor to acquire the information about a target under investigation. Based on its altitude above earth surface, platforms may be classified as

- Ground borne

- Air borne
- Space borne

Ground based platforms

The ground based remote sensing systems for earth resources studies are mainly used for collecting the ground truth or for laboratory simulation studies.

Air borne platforms

Aircrafts are generally used to acquire aerial photographs for photo-interpretation and photogrammetric purposes. Scanners are tested against their utility and performance from these platforms before these are flown onboard satellite missions.

Space-borne platforms

Platforms in space are not affected by the earth's atmosphere. These platforms are freely moving in their orbits around the earth, and entire earth or any part of the earth can be covered at specified intervals. The coverage mainly depends on the orbit of the satellite. It is through these space borne platforms, we get the enormous amount of remote sensing data and as such the remote sensing has gained international popularity.

Depending on their altitudes and orbit these platforms may be divided in two categories:

- Geostationary
- Polar orbiting or Sun-synchronous

Geostationary satellites

An equatorial west to east satellite orbiting the earth at an altitude of 35000 km. The altitude at which it makes one revolution in 24 hours, synchronous with earth's rotation. These platforms are covering the same place and give continuous near hemispheric coverage over the same area day and night. Its coverage is limited to 70 N to 70 Latitudes and one satellite can view one third of the globe. These are mainly used for communication and meteorological applications viz GEOS, METOSAT, INTELSAT and INSAT satellites.

Sun-Synchronous satellites

An earth satellite orbit in which the orbital plane is near polar and the altitude is such that the satellite passes over all places on earth having the same latitude twice in each orbit at the same local sun-time. Through these satellites the entire globe is covered on regular basis and gives repetitive coverage on periodic basis. All the remote sensing resources satellites may be grouped in this category. Few of these satellites are Landsat series, SPOT series, IRS series, NOAA, SEASAT, TIROS etc.

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.

Data Formats for Digital Satellite Imagery

Digital data from the various satellite systems supplied to the user in the form of computer readable tapes or CD-ROM. As no worldwide standards for the storage and transfer of remotely sensed data has been agreed upon, though the CEOS (Committee on Earth Observation Satellites) format is becoming accepted as the standard. Digital remote sensing data are often organised using one of the three common formats used to organise image data . For an instance an image consisting of four spectral channels, which can be visualised as four superimposed images, with corresponding pixels in one band registering exactly to those in the other bands. These common formats are:

- Band Interleaved by Pixel (BIP)
- Band Interleaved by Line (BIL)

- Band Sequential (BQ)

Digital image analysis is usually conducted using Raster data structures - each image is treated as an array of values. It offers advantages for manipulation of pixel values by image processing system, as it is easy to find and locate pixels and their values. Disadvantages becomes apparent when one needs to represent the array of pixels as discrete patches or regions, where as Vector data structures uses polygonal patches and their boundaries as fundamental units for analysis and manipulation. Vector format is not appropriate for digital analysis of remotely sensed data.

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 inorder 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

Pre-processing of the Remotely Sensed Images

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.

Image Arithmetic Operations

The operations of addition, subtraction, multiplication and division are performed on two or more co-registered images of the same geographical area. These techniques are applied to images from separate spectral bands from single multispectral data set or they may be individual bands from image data sets that have been collected at different dates. More complicated algebra is sometimes encountered in derivation of sea-surface temperature from multispectral thermal infrared data (so called split-window and multichannel techniques).

Addition of images is generally carried out to give dynamic range of image that equals the input images.

Band Subtraction Operation on images is sometimes carried out to co-register scenes of the same area acquired at different times for change detection.

Multiplication of images normally involves the use of a single'real' image and binary image made up of ones and zeros.

Band Ratioing or Division of images is probably the most common arithmetic operation that is most widely applied to images in geological, ecological and agricultural applications of remote sensing. Ratio Images are enhancements resulting from the division of DN values of one spectral band by corresponding DN of another band. One instigation for this is to iron out differences in scene illumination due to cloud or topographic shadow. Ratio images also bring out spectral variation in different target materials. Multiple ratio image can be used to drive red, green and blue monitor guns for color images. Interpretation of ratio images must consider that they are "intensity blind", i.e, dissimilar materials with different absolute reflectances but similar relative reflectances in the two or more utilised bands will look the same in the output image.

Image Classification

Raw digital data can be sorted and categorized into thematic maps. Thematic maps allow the analyst to simplify the image view by assigning pixels into classes with similar spectral values. The process of categorizing pixels into broader groups is known as image classification. The advantage of classification is it allows for cost-effective mapping of the spatial distribution of similar objects (i.e., tree types in forest scenes); a subsequent statistical analysis can then follow. Thematic maps are developed by two types of classifications, supervised and unsupervised. Both types of classification rely on two primary methods, training and classifying. Training is the designation of representative pixels that define the spectral signature of the object class. Training site or training class is the term given to a group of training pixels. Classifying procedures use the training class to classify the remaining pixels in the image.

Supervised Classification. Supervised classification requires some knowledge about the scene, such as specific vegetative species. Ground truth (field data), or data from aerial photographs or maps can all be used to identify objects in the scene.

Firstly, acquire satellite data and accompanying metadata. Look for information regarding platform, projection, resolution, coverage, and, importantly, meteorological conditions before and during data acquisition. Secondly, chose the surface types to be mapped. Collect ground truth data with positional accuracy (GPS). These data are used to develop the training classes for the discriminant analysis. Ideally, it is best to time the ground truth data collection to coincide with the satellite passing overhead. Thirdly, begin the classification by performing image post-processing techniques (corrections, image mosaics, and enhancements). Select pixels in the image that are representative (and homogeneous) of the object. If GPS field data were collected, geo-register the GPS field plots onto the imagery and define the image training sites by outlining the GPS polygons. A training class contains the sum of points (pixels) or polygons (clusters of pixels). View the spectral histogram to inspect the homogeneity of the training classes for each spectral band. Assign a color to represent each class and save the training site as a separate file.

Classification Algorithms. Image pixels are extracted into the designated classes by a computed discriminant analysis. The three types of discriminant analysis algorithms are: minimum mean distance, maximum likelihood, and parallelepiped. All use brightness plots to establish the relationship between individual pixels and the training class (or training site).

Minimum Mean Distance Minimum distance to the mean is a simple computation that classifies pixels based on their distance from the mean of the training class. It is determined by plotting the pixel brightness and calculating its Euclidean distance (using the Pythagorean theorem) to the unassigned pixel. Pixels are assigned to the training class for which it has a minimum distance. The user designates a minimum distance threshold for an acceptable distance; pixels with distance values above the designated threshold will be classified as unknown.

Parallelepiped In a parallelepiped computation, unassigned pixels are grouped into a class when their brightness values fall within a range of the training mean. An acceptable digital number range is established by setting the maximum and minimum class range to plus and minus the standard deviation from the training mean. The pixel brightness value simply needs to fall within the class range, and is not based on its Euclidean distance. It is possible for a pixel to have a brightness value close to a class and not fall within its acceptable range. Likewise, a pixel may be far from a class mean, but fall within the range and therefore be grouped with that class. This type of classification can create training site overlap, causing some pixels to be misclassified.

Maximum Likelihood Maximum Likelihood is computationally complex. It establishes the variance and covariance about the mean of the training classes. This algorithm then statistically calculates the probability of an unassigned pixel belonging to each class. The pixel is then assigned to the class for which it has the highest probability.

Unsupervised Classification

Unsupervised Classification. Unsupervised classification does not require prior knowledge. This type of classification relies on a computed algorithm that clusters pixels based on their inherent spectral similarities.

Steps Required for Unsupervised Classification

The user designates 1) the number of classes, 2) the maximum number of iterations, 3) the maximum number of times a pixel can be moved from one cluster to another with each iteration, 4) the minimum distance from the mean, and 5) the maximum standard deviation allowable. The program will iterate and recalculate the cluster data until it reaches the iteration threshold designated by the user. Each cluster is chosen by the algorithm and will be evenly distributed across the spectral range maintained by the pixels in the scene. The resulting classification image will approximate that which would be produced with the use of a minimum mean distance classifier (see above, "classification algorithm"). When the iteration threshold has been reached the program may require you to rename and save the data clusters as a new file. The display will automatically assign a color to each class; it is possible to alter the color assignments to match an existing color scheme (i.e., blue = water, green = vegetation, red = urban) after the file has been saved.

Gis Techniques

GIS is a computer based technology for handling geographical data in digital form. It is designed to capture, store, manipulate and perform analyses of spatially distributed data. It contains both geometry data (coordinates and topographical information) and attribute data (i.e., information describing the properties of geometrical objects). In GIS we can make the presentation of results in both graphic and report form, with a particular emphasis upon preserving and utilizing inherent characteristics of spatial data.

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.

Basic types of spatial data

There are four elementary types of geometric entities designed to encode spatial data: Points, lines, polygons and continuous surface (area).

Point Data: Points are the simplest type of spatial data. Points can be of two kinds: observations relating to discretely distributed phenomena such as oil and water wells and observations relating to continuous distributions such as weather station reporting precipitation measurements of soil temperature.

Line data: Line entities are linear features made of many points or straight line segments made defined of two or more pairs of coordinates. The line entities can be static (structural type) or dynamic (flow). An arc, chain, or a string is a set of x-y coordinate pairs describing a continuous complex line.

Polygon or area data: Polygons constitute the most common data type used in GIS. They are bounded regions determined by a closed continuous sequence of many segments. The boundaries may be defined by natural phenomena such a land forms or by man made features such as forest stand or land use units.

Continuous surface: Examples of continuous surfaces are elevation (as part of topographic data), rainfall, temperature, etc. Most of the GIS systems handle these, essentially three dimensional data as topographic data, usually as Digital Elevation Model (DEM).

Spatial data structure

Traditionally spatial data has been stored and presented in the form of a map. Three basic types of spatial data models have evolved for storing geographic data digitally. These are referred to as : Vector and Raster

Capabilities of GIS

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
v) Interpolation

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:

These involve the selective search and manipulation and output of data. Retrieval operation includes the retrieval of data using:

- Geometric Classifications
- Symbolic Specifications
- A name of 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 with out 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 of 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.

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.

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, substraction, 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

Nearest neighbor: This technique gives horizontal surfaces around each point. This technique is generally used for interpolation of the rainfall data. This provides weight to be used for the rain gauge stations, for finding average rainfall over a watershed.

Weighted average: A weighted average is taken of point elevation falling within a specified radius from the interpolation point. Weight is an inverse function of a distance between the point of unknown value (interpolation point) and that of known value (data points).

Weighted surface: Weighted surface fits a surface of n-degree using the elevations at points within a specified radius from the point of interpolation.

Trend surface: Trend surface fits an overall surface with the input data. It provides the global direction in which the variable changes.

Kriging/ geostatistical method: Kriging is a mathematical technique developed by D.G. Krige for application in mining industry in South Africa. The experimental semi variogram is calculated from the data. A standard semi variogram equation is fitted to the experimental data using regression technique. This fitted curve is used in the interpolation. For groundwater data the spherical theoretical semi variogram model is best suited.

Concluding Remarks

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.