APPLICATION OF REMOTE SENSING AND GIS IN HYDROLOGICAL INVESTIGATION

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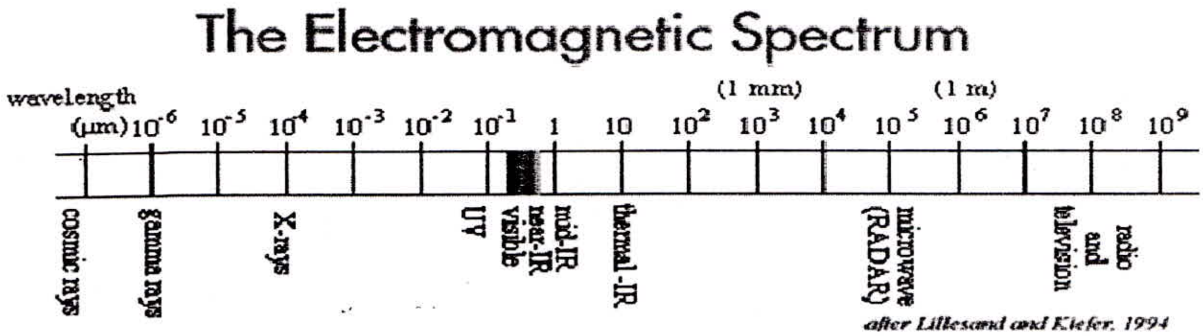
Remote Sensing and GIS are playing a rapidly increasing role in the field of hydrology and water resources development. Remote Sensing provides multi-spectral, multi-temporal and multi-sensor data of the earth's surface. One of the greatest advantages of using remote sensing data for hydrological investigations and monitoring is its ability to generate information in spatial and temporal domain, which is much crucial for successful analysis, prediction and validation. Satellite remote sensing is an obvious source of data for mapping and map revision because of their repetitive nature to cover a wide area at relatively low cost. For many hydrological 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, soils and rocks have to be considered. Also of interest are data related to where the demand of water for urban, irrigation and industrial supplies and social and economic data. In addition, information is also required such as locations and type of tubewells, rain and river gauges. Thus the fast storage, retrieval, display 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 Geographic Information System (GIS). Remote sensing and GIS help in creating an appropriate information base for efficient management of natural resources and environment. 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.
Remote sensing and GIS techniques are explained in the following sections followed by some of the applications in hydrology.

REMOTE SENSING TECHNIQUES

Remote sensing is generally defined as observing an object from a distance without having direct contact with it. Remote sensing systems are used to observe the earth's surface from different levels of platforms such as satellites and aircraft, and make it possible to collect and analyse information about resources and environment over large areas. Satellite imagery offers a number of advantages over conventional survey techniques:

- Areal synoptic coverage (gives areal information as against point information through conventional techniques)
- Repetitive global coverage (for monitoring change)
- Real time processing
- Sensing of surrogates rather than the desired specific observation
- Multispectral coverage
- More automation i.e. less human error

The basic principle involved in remote sensing is that each object, depending upon its physical characters, reflects, emits and absorbs varying intensities of radiation at different EMwavelength ranges. Using information from one or more wavelength ranges, it is possible to discriminate between different types of ground objects (e.g. water, dry soil, wet soil, vegetation, rocks etc.) and map their distribution on the ground. One of the important remote sensing technique use is aerial photography. Aerial photography has essentially remained to the visible part of the electromagnetic spectrum where it is only a very small fraction of the electromagnetic spectrum. Remote sensing techniques have extended the scope of utilisation of the electromagnetic spectrum to almost its entire range



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***, transmits 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. Nuclear reactions within the sun produce a full spectrum of EM radiation which is transmitted through space without major changes in its character until it reaches the atmosphere.

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
d) Analysis and Classification, and

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 analyzing 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;
Raster; and

Vector Data Formats

All spatial data models are approaches for storing the spatial location of geographic features in a database. Vector storage implies the use of vectors (directional lines) to represent a geographic feature. Vector data is characterized by the use of sequential points or vertices to define a linear segment. Each vertex consists of an X coordinate and aYcoordinate. Vector lines are often referred to as arcs and consist of a string of vertices terminated by a node. A node is defined as a vertex that starts or ends an arc segment. Point features are defined by one coordinate pair, a vertex. Polygonal features are defined by a set of closed coordinate pairs. In vector representation, the storage of the vertices for each feature is important, as well as the connectivity between features, e.g. the sharing of common vertices where features connect. The most popular method of retaining spatial relationships among features is to explicitly record adjacency information in what is known as the topologic data model. Topology is a mathematical concept that has its basis in the principles of feature adjacency and connectivity.

Advantages: Much greater precision in the definition of objects is possible by defining the geometric extent of the regions in which they occur. This means that one can draw far better maps with vector data than with raster data. Much less space is required to store all the information, since empty space on the map can be ignored.

Disadvantages: Topology between the geometric objects must be explicitly defined, though it can be done quite efficiently. The file structures required are more complex than the raster data files, and layer overlay operations can be very complex to perform. Spatial variability can be represented; using a *Triangulated Irregular Network*, but it is still not as effective as the use of regularly gridded data, and mathematical operations, such as derivatives, on layers or between two or more layers is all but impossible to perform.

Uses: Very widely used in such fields as computer cartography, analysis of networks, municipal databases that contain descriptions of building footprints, streets, etc. Common GIS packages that are vector-oriented include ARC/INFO and MapInfo.

Raster Data Formats

Raster data models incorporate the use of a grid-cell data structure where the geographic area is divided into cells identified by row and column. This data structure is commonly called raster. While the term raster implies a regularly spaced grid other tessellated data structures do exist in grid based GIS systems. In particular, the quadtree data structure has found some acceptance as an alternative raster data model.The size of cells in a tessellated data structure is selected on the basis of the data accuracy and the resolution needed by the user. There is no explicit coding of geographic coordinates required since that is implicit in the layout of the cells. A raster data structure is in fact a matrix where any coordinate can be quickly calculated if the origin point is known, and the size of the grid cells is known. Since grid-cells can be handled as two-dimensional arrays in computer encoding many analytical operations are easy to program. This makes tessellated data structures a popular choice for many GIS software. Topology is not a relevant concept with tessellated structures since adjacency and connectivity are implicit in the location of a particular cell in the data matrix. Several tessellated data structures exist, however only two are commonly used in GIS's. The most popular cell structure is the regularly spaced matrix or raster structure. This data structure involves a division of spatial data into regularly spaced cells. Each cell is of the same shape and size. Squares are most commonly utilized. Since regularly spaced shapes rarely distinguish geographic data, cells must be classified as to the most common attribute for the cell. The problem of determining the proper resolution for a particular data layer can be a concern. If one selects too coarse a cell size then data may be overly generalized. If one selects too fine a cell size then too many cells may be created resulting in large data volumes, slower processing times, and a more cumbersome data set. As well, one can imply accuracy greater than that of the original data capture process and this may result in some erroneous results during analysis. As well, since most data is captured in a vector format, e.g. digitizing, data must be converted to the raster data structure. This is called vector-raster conversion. The use of raster data structures allows that for sophisticated mathematical modelling processes while vector based systems are often constrained by the capabilities and language of a relational DBMS.

It is also important to understand that the selection of a particular data structure can provide advantages during the analysis stage. For example, the vector data model does not handle continuous data, e.g. elevation, very well while the raster data model is more ideally suited for this type of analysis. Accordingly, the raster structure does not handle linear data analysis, e.g. shortest path, very well while vector systems do. It is important for the user to understand that there are certain advantages and disadvantages to each data model.The selection of a particular data model, vector or raster, is dependent on the source and type of data, as well as the intended use of the data. Certain analytical procedures require raster data while others are better suited to vector data.

Advantages: Layer overlays are really simple, since all layers are defined with the same grid over the region. Topology is implicitly defined, since the location of each cell relative to all the others can be easily found.

Disadvantages: If you want to increase the *resolution* (that is, decrease the cell size) by a factor of two, the data set size will quadruple! In order to reduce this problem, various compression techniques, such as *quadtrees* and *run-length encoding*, are employed. Resolution is also problematic because the discretization process has an effect analogous to rounding of numbers, but in a spatial sense -- that is, what you see in the raster image is usually larger or smaller than the real-world equivalent. Objects smaller than one cell may not appear at all.

Uses: All satellite and aerial photograph data come in raster form. Each pixel represents the amount of light received by the sensor at a particular wavelength at the location. All satellites collect data from more than one wavelength, so a particular satellite pass will create an instant multilayer raster map of an area, as well as business for the magnetic tape industry. Common GIS packages using the raster model are GRASS and IDRISI. Raster data are best used for representing variables that vary continuously in space, such as elevations.

The connection between raster and vector data is critical in hydrology, perhaps more so than in other applications of GIS. Rivers are best represented as lines, and gaging stations and other control points on rivers like water right locations are best represented as points. However, the watershed areas draining to those points are best derived from digital elevation models, which are raster representations of land surface terrain elevation considered as a continuous surface. Moreover, precipitation, evaporation and other climatic variables are defined continuously through space and measured at particular points where there are climate stations. Being able to move back and forth smoothly between raster and vector representations of data is an important feature of spatial hydrology. A well constructed geospatial database for hydrology incorporates both vector and raster data in a tightly connected **raster-vector data model**. The features of the real world are depicted in vector data layers as points, lines and areas, and in the raster database as cells or zones of cells. While more spatially approximated than the vector database, the raster representation has the great advantage that various different kinds of hydrologic features can be represented in a single grid rather than having to be separated into different data layers as is the case with the vector representation.

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. Example retrieve 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.

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.

INTERPOLATIONPOINT

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 semivariogram is calculated from the data. A standard semivariogram equation is fitted to the experimental data using regression technique. This fitted curve is used in the interpolation. For groundwater data the spherical theoretical semivariogram model is best suited.

DIGITAL ELEVATION MODEL (DEM) OR DIGITAL TERRAIN MODEL (DTM)

DEM or DTM deals with the topographic elevation of the ground surface. Conventionally, the ground elevations are available in the topographic maps as contours, spot heights etc. In GIS, the information is available similar to this conventional form as vectors or points. Apart from this the data are also represented as raster and TIN model. Since, water flows under gravity from higher elevation to lower elevations, the DEM are very important input in hydrological studies. Using DEM, the surface is routed from upstream points to the catchment outlet. Other physical variables e.g. slope, aspect, drainage network, subwatersheds are also derived from DEM automatically.

The raster and TIN forms are useful input to hydrological models. Thus, the conventional forms of DEM such as vector, point are required to be converted to these forms. This is done through the interpolation techniques in GIS.

Triangulated Irregular Network (TIN): In this a network of triangles is created by joining point with techniques known as Thiessen polygons. At each apex of the triangles the height is known. The ground is represented as a plane surface with in a triangle. Input data to the model are spot height and contour data of the topographic maps. The triangles are so drawn such that sides of the triangles are the lines of slope or aspect change and the apex are the points where spot height is known.

OVERVIEW OF HYDROLOGICAL APPLICATIONS OF RS AND GIS TECHNIQUES

The availability of remotely sensed data and use of Geographic Information System (GIS) has provided significant impetus to hydrological analysis and design and their utilisation in water resources planning and development. Remote sensing and GIS techniques have been extensively used in various areas of water resources development and management, such as Flood plain management, Hydrologic modelling, Command area studies, Waterlogging and soil salinity, Snow cover studies, Sedimentation in Reservoirs etc.

LAND USE/LAND COVER MAPPING

Remote sensing technology has made most significant contribution in the area of land use mapping. Data collected by different sensors over various regions of electromagnetic spectrum help in differentiating one feature from the other. Landuse features can be identified, mapped, and studied on the basis of their spectral characteristics. Healthy green vegetation has considerably different characteristics in visible and near infrared regions of the spectrum, whereas dry bare soil has a relatively stable reflectance in both the region of the spectrum. Water shows very low reflectance in visible part of the spectrum and almost no reflectance in infrared part of the spectrum. Thus, by using multispectral data suitably, different ground features can be differentiated from each other and thematic map depicting land use can be prepared with satellite data. Landuse classification not only involves mapping of the area of a given crop or cover but also requires identification of the specific crop or forest species. Higher resolution multitemporal and multispectral data are ideal for this use.

LAND USE AND LAND COVER CLASSIFICATION SCHEMES

USGS CLASSIFICATION SYSTEM

The classification system is a 4-level hierarchical classification system. First two levels are rigidly defined. Next two level, users can defined based on their requirements. At the level 1 and 2, many land use types are placed based on functional aspects e.g. forest clearings are classified as forests, forest area inside the urban class are included in urban class, wetlands where timber produces are exploited are including in wetlands (not as forests) etc. Some classes takes precedence over other e.g. dense trees in residential areas are classified as urban.

URBAN OR BUILT-UP LAND

Urban land includes all buildings, residential areas, industrials, commercial complexes, institutional areas, strip development along roads, shopping complexes, transportation, communication, utilities etc.

AGRICULTURAL LAND

Agricultural land includes land that produces food and fibers. At level-2, the cropland and pasture are put in one class. Orchards (horticultural land) are another class at level-2. Orchards also include floriculture land.

RANGELAND

Range land are land with grasses and grass like plants, shrubs etc.

FOREST LAND

Forest land are land with at least 10% crown cover density of forests. The forests can be deciduous, coniferous or mixed.

WATER

Water are all bodies of water which are at least 200 m wide if linear and 16 ha in area otherwise. In water class lakes, reservoirs, canals, streams etc are included.

WETLAND

Wetland are area which have watertable at, near or above the ground surface for large part of the year for many years. Wet lands can be forested or non forested. Forested wetland can also produce timber, can be used for grazing etc.

BARREN LAND

Barren land includes land with no soil cover, thin soil cover or are rocky land. They support very sparse scrub. These land are not capable of supporting the plant life.

A classification system

	Level I	Level II
1	Agricultural land	1.1 Standing crop Irrigated land 1.2 Fallow land Unirrigated land
2	Waste	2.1 Sand dune like 2.2 Riverine grass 2.3 Barren land
3	Riverine	3.1 Dry river bed/ Ephemeral stream 3.2 Wet sand deposit 3.3 Swamp/ marshy vegetation
4	Water	4.1 Shallow water river/ canal 4.2 Deep water in river/ headwork pondage 4.3 Very deep water in reservoir
5	Forest	5.1 Deciduous forest 5.2 Evergreen forest
6	Wetland	
7	Built-up area	
8	Snow/ cloud	

FLOOD PLAIN MANAGEMENT

Reliable data on river morphology, river meandering, extent of flooding and duration is required for proper planning of flood control projects. In the conventional methods of flood risk zoning, the flood discharge is routed through the river reach to estimate the likely inundation due to spilling over the banks/embankments based on topographic contour maps available and the configuration of the river geometry obtained through land surveys. Continuos availability of satellite based remote sensing data has made the understanding of dynamics of flood events much easier. The satellite remote sensing techniques provide a wide area synoptic coverage, repetitiveness and consistency, which enable the collection of information on all major flood events on a reliable basis.

Remote sensing can provide information on flood inundated areas for different magnitudes of floods so that the extent of flooding in the flood plains can be related to the flood magnitude. Duration of flooding can be estimated with the help of multiple coverage satellite imagery of the same area within 2/3 days by satellites. High-resolution satellite data provides information on the floodplain and effectiveness of flood control works. Inundation extent for specific flood return periods can be estimated. Using close contour information inundation extent for given level elevation, can be estimated which is a vital input for risk zone mapping.

Indian Remote Sensing Satellite are being used for obtaining information on various flood characteristics. The IRS series IRS-1A, IRS-1B and IRS-P2 has got onboard sensors LISS-I and LISS-II which collects information in optical region of the EMS at spatial resolution of 36m and 72m with a repetivity of 22 and 24 days (IRS-P2). The recently launched IRS-1C which is unique in its nature has got three sensors onboard PAN, LISS-III and WiFS which provides information at spatial resolution of 5.6m, 20m and 188m respectively also the IRS-P3 has got WiFS sensor on board with revisit period once in 5 days. The WiFS sensor which has got wide swath about 800 kms and a repetivity 2/3 days proves to be very effective in monitoring floods.

In addition to IRS satellites, NRSA has been receiving data from meteorological satellites, NOAA (AVHRR) and Landsat 5 Thematic Mapper data which has hot 30 meters spatial resolution and 16 days repetivity and microwave data from European Remote Sensing satellite (ERS) which has got C-band SAR sensor onboard. Data from Canadian Microwave satellite RADARSAT is also planned.

GIS provides a broad range of tools for determining area affected by floods and for forecasting areas that are likely to be flooded due to high water level in a river. When spatial data are used in an information system, one tends to speak of a spatial information system. The term spatial information system can be considered as the general discipline for those information system which deals with spatial data. Spatial data has a physical dimension and geographic location. Spatial data stored in the digital data base of the GIS, such as a digital elevation model (DEM), can be used to predict the future flood events. The GIS data base may also contain agriculture, socio-economic, communication, population and infrastructural data. This can be used, in conjunction with the flooding data to adopt an evacuation strategy, rehabilitation planning and damage assessment in case of a critical flood situation.

HYDROLOGIC MODELLING

In the early days GIS were mainly used as hydrological mapping tools. Nowadays, they play a more important role in hydrological model studies. Their applications span a wide range from sophisticated analyses and modelling of spatial data to simple inventories and management tools, and can be found in many fields, such as land planning, natural resource management, environmental assessment and planning, ecological research etc. Distributed rainfall runoff modelling requires a large number of parameters to describe local topography, soil type, land use, and can be substantially facilitated by the use of GIS. The application of GIS has enhanced the capacity of models in data management, parameter estimation and presentation of model results, but GIS can not replace hydrological models in solving hydrological problems.

Due to its data handling and manipulation capabilities, GIS is increasingly being used as an interface and data manager for hydrologic models. There are four levels of linkage of hydrological model with GIS. These levels vary from essentially considering GIS and the model as separate systems to fully integrating the model and GIS. The lowest level of integration consists of using GIS as an aid in developing the input data file for the model. A user then takes the preliminary files and modifies them to produce a complete input file in the format required by the model. A similar procedure in the opposite direction can be applied to the outputs of the model in order to present and store them in GIS. This approach enables one to use an existing GIS and an existing model without modification to either but requires the most of user's effort. The next level of integration is to use an interfacing program specifically written to communicate between the GIS and the model. The interface program may serve as a control program issuing commands to the GIS and the model. Output from the GIS is converted into the proper input format for the model and then read by the model. Output from the model may likewise be converted to a GIS format and then displayed by the GIS. All these operations are carried out under the control of the interface program. A third level of integration occurs when the interface program is incorporated into the model. This requires modification to the input/output routines of existing models or developing special input/output routines for new models. Some programming may also have to be done within the GIS to alter its input/output structure to make it more compatible with that of the model. If one is making extensive changes to a model or developing a new model, this level of integration would be appropriate. The highest level of integration occurs when the model and GIS are essentially a single, integrated unit. One way of achieving this is by programming the model using the programming language appropriate to the GIS being employed. This makes GIS a master module, which controls the model runs.

CONCLUDING REMARKS

GIS, in combination with remote sensing technologies, is being successfully used in water resources studies. The availability of frequent data from remote sensing on a relatively large scale allows hydrological problems to monitor through various seasons and even from year to year. Such monitoring is, for the most part, highly cost effective, especially when the alternative would necessiate field surveys. In relatively inaccessible area, remote sensing may be the only way to collect the necessary data. This data alongwith ancillary data can be used and integrated in GIS model. The reason of adopting GIS technology is because it allows the spatial information to be displayed in integrative ways that are readily comprehensible and visual. Remote sensing is now being widely regarded as a layer for updating the data base 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 GIS provides a methodology by which data layers can be interrelated in order to arrive at wider decisions. The integrated use of remote sensing and GIS technology can not only improves the quality information previously unavailable to be economically produced.

The research needs in the area of water resources are as follows:

- First and very important aspect is the data availability and compatibility in any GIS related study. Spatial information required for water resources studies should be readily available for timely execution. The data banks should provide digitized maps and their spatial data compatible with various systems. Such data availability could significantly speed up the analysis.
- One difficult task in incorporating GIS in water resources modelling is the interfacing of water system models with the GIS. Automation of interfacing tasks is one of the areas to be researched in incorporating GIS and available models.
- The recent developments of Decision Support System (DSS) to assist with water resources decision making holds the key for integration of GIS and water resources models
- Another area of potential research to further enhance the modelling process is the integration of expert systems and GIS. Expert GIS systems can be used to provide regulatory information by linking regulatory facts stored in a data base to sites located in a GIS through an expert system query interface.
- Further research is needed for comparing the GIS packages available in the market and their positive and negative aspects, providing check lists for GIS users.