LECTURE-8

Fundamentals of GIS its Application in Hydrology

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Computers have been used in the field of hydrology and water resources for many years as means of organising information in order to solve management problems. At the same time the use of Geographical Information Systems (GIS) became widespread during the last decade. This technology has altered traditional way of modelling in hydrology and water resources management and continues to do so.

The term Geographic Information System may be explained as follows:

'**G**eographic' stands for spatial data. These are the data which are associated with a specific place or places on Earth's surface, sometimes called as 'geo-referenced'.
'**I**nformation' may be viewed as data with added knowledge.
'**S**ystem' refers to the integration of user and machine (hardware and software) able to input, manipulate and present data.

Therefore, we can say that GIS is a general purpose 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.

Database provides facilities to perform several operations commonly required in manipulation of attribute data. These operations include:

- Retrieving data from the existing datasets
- Updating, editing and/or transforming the existing datasets
- Inserting new data into existing datasets
- Adding new datasets to the database
- Deleting data from existing datasets
- Removing datasets from the database

Components of spatial data

Spatial data have three major components: geographic position, attributes or properties, and time or dynamics

Position: Position refers to the fact that each feature has a location that must be specified in a unique way. The location can be absolute or relative. Absolute location is defined using a coordinate system like Cartesian (X,Y) or global geographic (latitude/longitude), eastings and northings, row and column position describing a position on a grid etc. Relative location is given with reference to some other object, e.g. as topologic position, which is described through a relationship to other objects, such as "adjacent to" or "intersects with".

Attribute: Attributes are often termed as non spatial data since they do not in themselves represent location information. An attribute is a characteristic of an entity.

Time: Time is important and critical since the geographic information is referenced to a point in time or to a period of time. Knowing the time where geographic data were collected is of utmost importance for using these data appropriately, e.g., an area may be covered by forest one year and have been clear out the next.

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
Image.

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 a Ycoordinate. 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.

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 a large data volumes, slower processing times, and a more cumbersome data set. As well, one can imply an 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.

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

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 is 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.

DIGITAL ELEVATION MODELS

One of the capabilities of GIS is the description of the topography of a region. Techniques used in the computer description of topography are called as Digital Elevation Model (DEM). DEM's are arrays of numbers that represent the spatial distribution of terrain altitudes. Main data sources for DEM's are ground surveys, existing topographic maps, photogrammetric stereomodels and surveys done by radar or laser altimeters carried in aircrafts and spacecrafts.

Various data structures are in use for DEMs, each with their own merits and shortcomings. There is no structure which satisfies all requirements; much will depend on the purpose and also on the computer facilities available. The basic structures are the line model, the triangulated irregular network and the grid network.

The classical form of representing topography is the contour line mapping. The contours can be represented digitally as a set of point to point paths (vectors) of a common elevation. The line model describes the elevation of terrain by contours (stored as Digital Line Graphs i.e. the x,y coordinate pairs along each contour of specified elevation). Typical GIS operations based on the line model are carried out by overlaying the contours on to thematic maps or remotely sensed classifications.

An alternative approach to producing DEM's relies upon determination of significant peaks and valley points in the terrain, which is then represented by a collection of irregularly spaced points connected by lines. The TIN model splits up the true surface into triangular elementary planes. The terrain surface is sampled by points (nodes) that are located at positions which capture the terrain characteristics.

The grid based methods may involve the use of a regularly spaced triangular, square or regular angular grid. The element area is the cell bounded by three or four adjacent grid points, depending upon the method. The raster based GISs use the square grid networks. The advantage of the regular grid method is the simplicity of the data storage usually as sequential z coordinate along the x (or y) direction, with a specified starting point and grid spacing.

The most common method of acquiring elevation data in a digital raster format is to digitize the contours from a topographic map and apply an interpolation method to transform the contour data into a DEM. Although the quality of DEM essentially depends on the topographic map used, the interpolation algorithm used for DEM resampling has also a significant influence. The interpolation algorithm used for DEM resampling may be designed according to different requirements. Many technique aim at minimising the RMS-error; this criterion is the one most commonly applied in DEM quality assessment. On the contrary, some other techniques tend to preserve the terrain texture.

DEM can be put in use in variety of applications. The most common products derived from DEM relate elevation, slope, aspect, convexity/concavity of terrain etc. Considerable research has been carried out in the field of drainage network extraction and watershed boundary delineation by hydrologists and geologists.

APPLICATIONS IN HYDROLOGY

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. Remote sensing data is one of the major input in GIS based studies, therefore in the following applications, use of remote sensing has also been discussed.

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 and configuration of the river geometry obtained through land surveys. Continuous 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 magnitude 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. High-resolution satellite data provides information on the floodplain and effectiveness of flood control works. Extent of inundation for specific flood return periods can be estimated. Using close contour information, inundation extent for given elevation, can be estimated which is a vital input for risk zone mapping.

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. Spatial data stored in the digital database of the GIS, such as a digital elevation model (DEM), can be used to predict the future flood events. The GIS database may also contain agriculture, socio-economic, communication, population and infrastructure 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.

Mapping and Monitoring of Watersheds

Proper planning of watersheds is essential for the conservation of water and land resources and their productivity. Characterisation and analysis of watersheds are a pre-requisite for this. Watershed characterisation involves measurement of parameters of geological, hydro geological, geo-morphological, hydrological, soil, land cover/land use etc. Remote sensing via aerial and space borne sensors can be gainfully used for watershed characterisation and assessing management requirements and periodic monitoring. The various physiographic measurements that could be obtained from remotely sensed data are size, shape, topography, drainage pattern and landforms. The quantitative analysis of drainage networks enables relationships between different aspects of the drainage pattern of the basin to be formulated as general laws and to define certain useful properties/indices of drainage basin in numerical terms. The laws of stream numbers, stream length and stream slopes can be derived from measurements made in the drainage basin. Remote sensing along with ground based information in GIS mode can be used for broad and reconnaissance level interpretations for land capability classes, irrigation suitability classes, potential land users, responsive water harvesting areas and monitoring the effects of watershed conservation measures. Correlations for runoff and sediment yields from different watersheds versus land use changes and land degradation could also be established.

Command Area Studies

Water management in command areas requires to be given serious attention in view of the disappointing performance of our irrigation projects despite huge investments. The command area is the total area lying between drainage boundaries, which can be irrigated by a canal system. Remote sensing can play a useful complimentary role in managing the land and water resources of command areas to maximize the production. Management of water supplies for irrigation in command areas is a critical problem to tackle with vis-a-vis limited quantities. This requires information on total demand and the distribution of demand for irrigation in command areas. Moreover the vastness of area involved, time constraints and yearly changes demand fast inventory of the situation. With more area being brought under irrigation, crop monitoring also becomes essential for estimating agricultural production and efficient planning of water management. It is in all these; remote sensing can be looked upon as an aid in planning and decision-making. The usefulness of remote sensing techniques in inventory of irrigated lands, identification of crop types, their extent and condition and production estimation have been demonstrated in various investigations. Conjunctive use planning of surface and groundwater can be done using the remotely sensed information on surface water assessment in conjunction with ground-based data on groundwater availability. This would permit development of conjunctive use models for land water allocations in GIS environment.

Waterlogging and Soil Salinity

Water logging and soil salinity are some of the major land degradation processes that restrict the economic and efficient utilization of soil and land resources in command areas. To asses water logging in command areas, multi-spectral and multi temporal remote sensing data are very useful. The satellite data thus provide a quick and more reliable delineation of the waterlogged areas and inundation. The spatial distribution of soil affected by 'positional water logging' (i.e., that due to its location in the landscape) can be modeled with digital topographic data using the concept of contributing area. This water logging depends on two topographic factors 1) the local slope angle 2) the drainage area. The probability of water logging increases with the contributing drainage area and decreases with increasing local slope angle. As the water logging phenomenon is related with topography, so Digital Terrain Modelling (DTM) can aid in detecting the waterlogged areas. DTM provide information regarding slope, aspect etc., which in turn provide information about the areas susceptible to water logging.

One of the common practices in command area for observing the waterlogged area is to take observation in the existing open wells at regular intervals i.e. twice a year in the pre and post-monsoon seasons. The data are also collected for the quality of water. The information thus collected is used to draw hydrographs and depth of water table to prepare the vulnerability maps. These maps can help in the identification of waterlogged zones in a command area. Using field data, which are available in the form of point data, groundwater depth distribution maps can be prepared in GIS. With the help of these maps shallow GW areas etc. or in other words the areas susceptible to water logging can be identified. The areas falling within 0-1.5 m range generally indicate waterlogged or salt-affected patches depending primarily upon the soil characteristics.

Snow Cover Studies

Snow is an important phase of the hydrologic cycle over a significant part of year in mountainous region. Snow cover measurements are difficult and estimates are not reliable because of the hostile climatic conditions and the remoteness. Once on the ground, snow is frequently deposited in an irregular way and redistributed by the wind. Thus, over a short distance, snow depths, and hence the water equivalents, may show wide variation. Consequently, point measurement of the snow cover provides insufficient information. Conventional methods have limitations in the monitoring of snow-covered area in the Himalayan basins because of inaccessibility. Snow by virtue of the high reflectivity, is one of the objects on the surface of earth, which is readily detected or identified on any visible, or near IR remotely sensed image. Fresh snow has a high reflectivity in the visible wavelengths. However, it decreases as the snow ages. The reflectivity of snow is dependent on many snow characteristics such as shape and size of snow crystals, liquid water content (especially of the near surface layers), impurities in the snow, depth of snow, surface roughness etc. Since, very little information on snow is collected regularly in the mountainous regions, remote sensing remains the only practical way of obtaining some relevant information of the snow cover in the large number of basins in the mountains. At present the visible, near IR and thermal IR data from various satellites (Landsat, IRS, NOAA) are being used for mapping the area extent of snow cover in the mountainous basins. Visible and near infrared wavelengths, because they do not penetrate far into the snow pack, mainly provide information about the surface of the snow pack. Microwave remote sensing is promising because of its ability to penetrate the dry snow-pack, and its capability to acquire data in cloudy or night time conditions. Snow cover data extracted by satellite remote sensing is immediately useable in snowmelt runoff models. In addition to extent of snow cover, satellite data are useful in computation of snow water equivalents.

Reservoir Sedimentation

A great amount of sediment is carried annually by the Indian rivers down to the reservoirs, lakes, estuaries, bays, and oceans. Soil is eroded due to rainfall and winds, resulting in tremendous sediment movement into water courses by flood and storm waters. The impact of sediment erosion, transport and deposition is widespread. Deposition of coarse sediments reduces the reservoir storage and channel conveyance for water supply, irrigation, and navigation and cause extensive disturbance to streams. Suspended sediments reduce water clarity and sunlight penetration, thereby affecting the biotic life. As the sediment settles to the bottom of water bodies, it buries and kills vegetation and changes the ecosystem.

Conventional techniques for sedimentation quantification are: a) direct measurement of sediment deposition by hydrographic surveys, and b) indirect measurement of sediment concentration by inflow - outflow method. Both these methods are laborious, time consuming, and costly and have their own limitations. Sampling and measurement of suspended sediments is a tedious and expensive program for either in-situ or laboratory work.

With the introduction of remote sensing techniques in the recent past, it has become cheap and convenient to quantify sedimentation in a reservoir and to assess its distribution and deposition pattern. Remote sensing techniques, offering data acquisition over a long time period and broad spectral range, are superior to conventional methods for data acquisition. The advantage of satellite data over conventional sampling procedures include repetitive coverage of a given area (16/22 days) a synoptic view, which is unobtainable by conventional methods, and almost instantaneous spatial data over the areas of interest. The remote sensing techniques provide synoptic view of a reservoir in a form different from that obtained with surface data collection and sampling.

Water Quality Studies

Water quality is a general term used to describe the physical, chemical, thermal and/or biological propertied of water. In recent times, the alarming proportions of water quality deterioration necessitate rapid monitoring for efficient checks to prevent further deterioration and to cleanse our polluted water sources. Moreover surveillance of water quality is an important activity for multiple uses such as irrigation, water supply, etc. We usually define substances affecting water quality as coming from either point or non-point sources. Point sources are associated with substances that can be traced to a single source, such as a pipe or ditch. Non-point substances are more diffuse and associated with the landscape and its response to water movement and land use. All human and natural activities contribute non-point substances to runoff water thus, affecting its quality.

A combination-ground (water) and remote sensing-measurements are required to collect the data necessary to develop and calibrate empirical and semi-empirical models and validate the physically based models. Water samples analysed for substance of interest (i.e., suspended sediment, chlorophyll) should be collected at the same time (or on the same day) that the remote sensing data is collected. Location of sample sites should be determined with GPS (or other available technique) so that the correct data (pixel information) can be extracted from remote sensing for comparison. Remote sensing applications to water quality are limited to measuring those substances or conditions that influence and change optical and/or thermal characteristics of the apparent surface water properties. Suspend sediments, chlorophyll (algae), oil and temperature are water quality indicators that can change the spectral and thermal properties of surface water and are most readily measured by remote sensing techniques.

Groundwater Studies

Remote sensing system is quite helpful in groundwater exploration as the remotely sensed data provide a large area synoptic view with high observational density. The common current remote sensing platforms record features on the surface. Most of the information for ground water, as yet, has to be obtained by qualitative reasoning and semi quantitative approaches. The remote sensing information is often of surrogate nature and has to be merged with geo-hydrologic data to become meaningful. The vegetation can be used as an indicator if local knowledge is available and the types can be identified on the satellite data. Apart from the contribution which remote sensing can make to understanding regional hydrogeology-necessary for managing groundwater resources-perhaps the strongest application for the management in the evaluation of the recharge, the groundwater drafts for irrigation and the identification of flow systems in areas where there is paucity of geo-hydrological data. Surface conditions, soils, weathered zones, geomorphology and vegetation determine the recharge, suitability for artificial recharge and soil and water conservation measures which can affect the recharge.

Groundwater vulnerability to pollution is also directly related to surface conditions. Indexing methods, group depth to water table, net recharge, topography, impact of vadose zone media and hydraulic conductivity of the aquifer (leading to the acronym DRASTIC) into relative ranking scheme that uses a combination of weights and ratings to produce numerical values.

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. GIS has evolved, as a highly sophisticated data base management system to put together and store the voluminous data typically required in hydrologic modelling. 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.

One typical application of a GIS in watershed analysis is predicting the spatial variability of surface erosion from spatial data sets obtained from maps of the vegetative cover, soils, and slope of the area. Solutions of a surface erosion (soil loss) prediction model, for example, the Universal Soil Loss Equation (USLE) or its modifications, combine the spatial data sets, their derivatives, and other information necessary to predict the spatial variability of surface erosion on a watershed. This analysis can determine areas of potentially severe surface erosion, providing an initial step in the appraisal of surface erosion problems.

GIS for Decision making

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 an 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. However, the weightages as well as the proper use of such data is still problematic.

A decision support system (DSS) can be defined as an interactive computer based system, which permits a combination of knowledge sources from various domains in order to help decision makers to solve complex problems. DSS have evolved from practices in the management of information systems, particularly in the field of data processing in business sciences. When applied to water management, a DSS requires a spatial dimension and is therefore usually incorporated in a GIS, thus forming a Spatial Decision Support System (SDSS). Currently available DSS and SDSS are being used for decision making in water resources planning and management.

CONCLUSIONS AND FUTURE NEEDS

A combination of remote sensing data, ground truth, (e.g. from modern hydrometric equipment) and powerful software domains such as GIS give the water resources manager extremely powerful tools to help solve their problems. 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 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 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. Remote sensing can provide many of the necessary data to supplement conventional data and also provide new data types and forms that will help to tackle previously unsolvable questions.
- 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.

- One difficult task in incorporating GIS in water resources modeling 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 Systems (DSS) to assist water resources decision making holds the key for integration of GIS and water resources models
- Another area of potential research to further enhance the modeling 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 database 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 characteristics, providing check lists for GIS users.

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