Remote Sensing and GIS in Hydrology

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INTRODUCTION

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

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

For many water related studies, remote-sensing data alone are not sufficient; they have to be merged with data from other sources. Hence a multitude of spatially related (i.e. climatic and geographic) data concerning rainfall, evaporation, vegetation, geomorphology and soils has to be considered. In addition, information is also required such as locations and type of tube wells, rain and river gauges etc. Thus the fast storage, retrieval, displays and updating of map contents are important functions. A system that can store the data, select and classify the stations and perform mathematical and sorting operations is called a database and information can be extracted from it for a given purpose. If this information can also be displayed in the form of maps, we can speak of geographic information. So this complete set of information forms the GIS.. GIS 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. The use of remote sensing data in GIS is shown in Fig. 1.

Problems associated with water resources development and efficient utilization are varied and too many in nature like frequent floods and droughts, waterlogging and salinity in command areas, alarming rate of reservoir sedimentation due to deforestation, deteriorating water quality and environment and snow cover assessment in remote and inaccessible areas. All these are required to be tackled through systematic approaches involving judicious mix of conventional

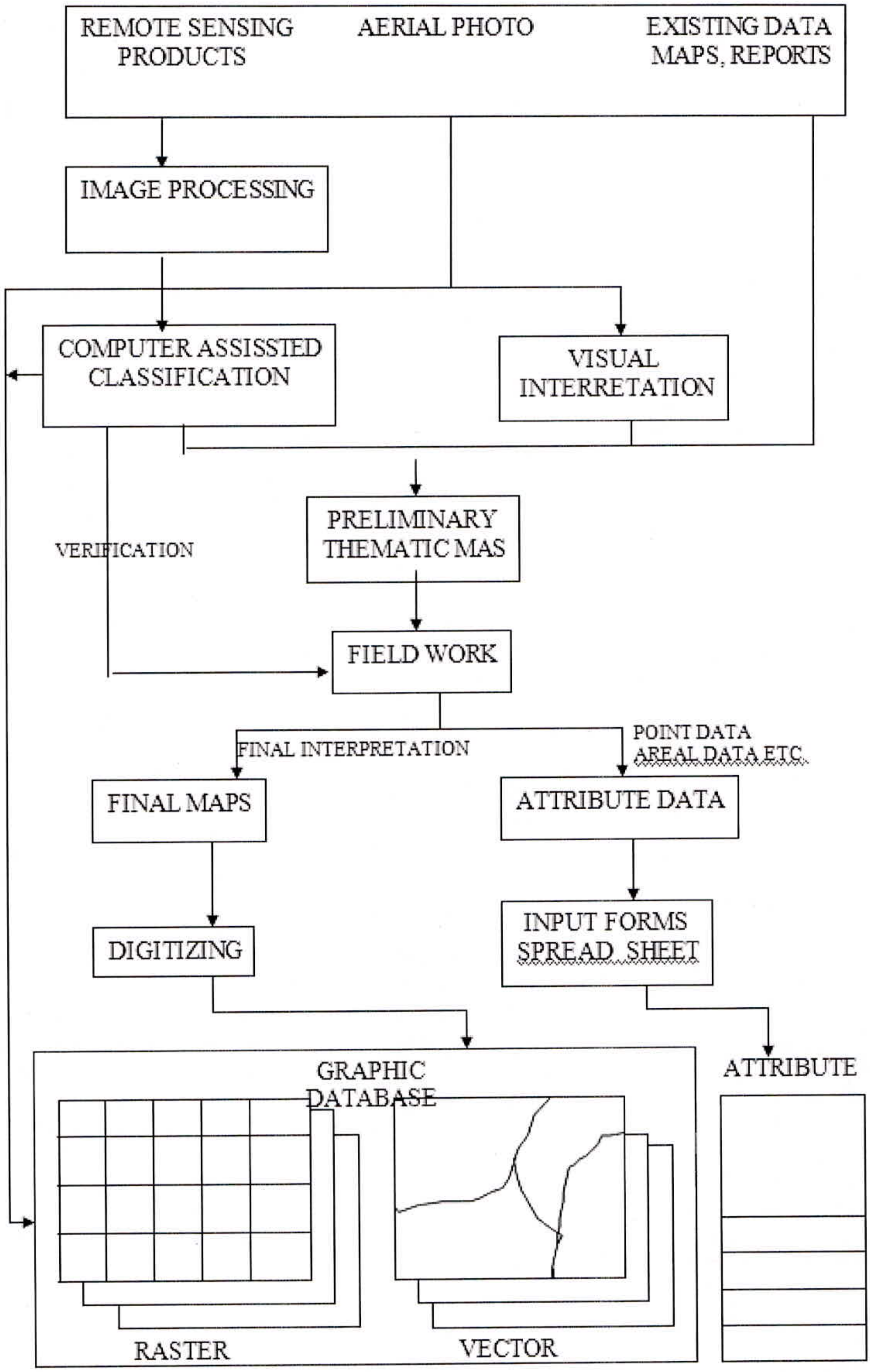

Fig. 1 Remote sensing products in a GIS

methods and remote sensing data in GIS environment. The availability of remotely sensed data and use of GIS has provided significant impetus to hydrological analyses and design and their utilization 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 land use/cover classification, Flood plain management, Command area studies, waterlogging and soil salinity, snow cover studies, sedimentation in reservoirs and water quality studies, etc. which are defined below in brief.

LAND USE/LAND COVER CLASSIFICATION

Land cover i.e. the cover on the earth's surface with soil vegetation, water, cities etc. depends on natural factors and human activities. Mutli-spectral classification of land cover was one of the first well-established remote sensing applications for water resources. Due to agriculture, forest management and urbanisation the physical characteristics of the land surface and upper soil as well as the evpotranspiration process, which is strongly related to the type of vegetation, are changed. As a result the amount of runoff, the soil moisture and groundwater recharge are strongly affected by land use changes. Numerous investigators have used classification of land cover from satellite data as input to various water resources studies. Land use 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, using multi-spectral data suitably, different ground features can be differentiated from each other and thematic map depicting land use can be prepared with satellite data. Land use data devised from remote sensing are an ideal database for distributed hydrologic modelling changes. In many hydrological models the parameters of vegetation related model components (e.g. for interception and evapotranspiration) are chosen dependent on the land use. Land use/land cover information derived using remote sensing techniques have been the most widely investigated application of remote sensing in hydrologic modeling. The bulk of these efforts have centered on using the land use information to estimate SCS runoff curve numbers for stream flow forecasting.

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, geomorphological, and 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

Waterlogging 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 waterlogging 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 waterlogging' (i.e., that due to its location in the landscape) can be modeled with digital topographic data using the concept of contributing area. This waterlogging depends on two topographic factors 1) the local slope angle 2) the drainage area. The probability of waterlogging increases with the contributing drainage area and decreases with increasing local slope angle. As the waterlogging 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 waterlogging.

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 waterlogging 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.

HYDROLOGICAL MODELING AND GIS

A hydrological model is a mathematical model used to simulate river or stream flow and calculate water quality parameters. Runoff estimation is useful in water resources planning, design of hydraulic structures, bridges etc. Impact of land use/ climatic changes on hydrological cycle can be studied through simulation studies. Inundation mapping can also be done in river basin using hydrologic/ hydraulic mathematical models. Remotely sensing data are important data source in modeling. Land use and its management practices affect runoff from basins. Land use and cover maps, up to level IV, can be prepared using remotely sensed data. Soil texture and types can also be interpreted. SRTM (Shuttle Radar Topographic Mapping Mission) Digital elevation models (DEM) are available at 90 m spatial resolution and 1 m least count for the world. Rainfall data are available at 15' geographic and 3 hourly temporal resolution from TRMM (Tropical Rainfall Measuring Mission). Water and land temperature can be monitored using satellite data.

GIS is a useful tool in data preparation for hydrologic models. DEM can be used for extracting catchment and channel characteristics in GIS. Semi- distributed models require division of basin in to sub basins. Sub basins can be delineated automatically using DEM. Catchment characteristics, namely, area, perimeter, longest flow path; flow path up to the centroid, average slope can be computed using DEM in GIS. For channels, length, average slope and cross section can be extracted. In GIS framework, set up files for the models can be prepared. These files can be used in model simulation. Examples of ARC View GIS interfaces are GeoHMS, GeoRAS, AvSWAT, Mike 11 GIS for HEC HMS, HEC RAS, SWAT and Mike 11 hydrological models respectively Arc View is widely used software for providing interface for data preparation for hydrological models. Extensions are written for several hydrological models. These extension are written using scripting language namely Arc Macro Language (AML). To use an extension, the extension is required to be activated in Arc View menu. Special menu items and icons are added after the extension is selected. The menu items/ icons can be used for data preparation of the hydrological models.

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 geohydrologic 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 geohydrological 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 depth and quality is studied in GIS through kriging interpolation technique. Water quality variables e.g. EC, RSC, HCO3 etc. can be interpolated using the technique. In these applications, sample locations can be important. For example, samples are taken from working tube wells, which may be in general of good quality and poor water-quality is under represented. Range can be of order of 10 to 100 km. Models can be exponential, spherical etc.

Groundwater potential and quality can be mapped in GIS environment. Various layers namely slope, geology, hydromorphogeology, distances to drainage channel, tanks and lineaments, depth to water table, depth of weathered zone can be overlaid and integrated on GIS environment to obtain groundwater potential map. Similarly, layers namely magnesium, incrustation problem, TH, TDS can be integrated to obtain quality map in incrustation and corrosion problem areas. 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.

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 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 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 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 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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