REMOTE SENSING AND GIS APPLICATIONS IN HYDROLOGY

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Remote sensing and Geographic information system (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 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. The instruments or devises used are called remote sensors. These record electromagentic 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 imagery offer 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

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). 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.

One of the capabilities of GIS most important to water resources management studies is the description of the topography of a region. Digital Elevation Model or DEM provides a digital representation of a portion of the earth's terrain over a two dimensional surface. DEMs have potentially proved to be a valuable tool for the topographic parameterization of hydrological models especially for drainage analysis, hillslope hydrology, watersheds, ground water flow and contaminant transport etc.

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.

1.0 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.

2.0 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 provides a wide area synoptic coverage, repetitiveness and consistency, which enables 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.

3.0 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.

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.

4.0 Command Area Studies

The land use changes with time need a continuous monitoring and satellite data have been extensively used for mapping and monitoring of surface water bodies/reservoirs, identification of water logged areas in the command areas, and inventory of crop lands and cropping patterns. By using multispectral satellite data suitably, different ground features can be differentiated from each other and thematic maps depicting land use can be prepared.

Water management in command areas requires to be given serious attention in view of the disappointing performance of our irrigation projects despite huge investments. Remote sensing can play a useful complimentary role in managing the land and water resources of command areas to maximize the production.

Multispectral satellite imagery in near infrared bands particularly (0.75 - 1.0 µm range) are ideal for inventorying of surface water bodies like ponds, tanks and reservoirs. The assessment of irrigation potential under various irrigation waterbodies in the beginning of the agricultural season would facilitate formulating suitable cropping programmes. Monitoring of these sources over the season would help in achieving the desired and targeted level of irrigation.

Conjunctive use planning of surface and ground waters can be done using the remotely sensed information on surface water assessment in conjunction with ground based data on ground water availability. This would permit development of conjunctive use models for land water allocations. 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 areas involved, time constraints and yearly changes demand fast inventory of the situations. 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 has been demonstrated in various investigations.

5.0 Crop Identification

An accurate and timely crop production forecasting is possible using remote sensing technique by identifying the crop cover. This technique is well established for pre-harvest acreage estimation of major crops like paddy, wheat, cotton, sugarcane, soybeans, sorghum etc. Various crops can be identified using multispectral and multidate imagery. Simultaneous images of the same area, acquired in various wavelength regions, provide complementary information, which greatly facilitates in the recognition of various crop types.

The crop identification and acreage estimation procedure broadly consists of identifying representative sites of various crops/landcover classes on the image based on the ground truth collected, generation of signature for different training sites and classifying the image using training statistics. Change in the field condition becomes the major clue of identification when utilizing multidate imagery in conjunction with a crop calendar of the area/region. Multidate imagery helps in confirming earlier identification and often crops which can not be identified in the first instance, can be identified in later imagery.

Natural calamities (flood and drought) and stresses due to nutrient deficiency, salinity and alkalinity, insect damage, diseases etc. affect crop growth and consequently the yield. The estimated crop loss due to pests alone is about 20 percent of the potential production. Significant portion of these losses could be prevented if an unbiased, objective and timely information system could provide early warning on the intensity of impending agricultural hazard. Since remote sensing data analysis and interpretation is connected with the surface reflectance of the crops, particularly leaves which are the primary consideration for insects and pest damage, the remote sensing technology can be utilised for detecting the changes caused to healthy plants by insects and disease. Different projects like Crop Production Forecasting (CPF), Crop Stress Detection (CSD), and Crop Yield Monitoring (CYM) have been taken up under IRS-UP (Utilisation Program) to develop appropriate techniques.

6.0 Precipitatipon Studies

Rainfall is highly variable in space and time. Ground based measurement of rainfall using a network of rain gauges does not always give the true representative picture of rainfall owing to difficulties in installation and operation of rain gauges in inaccessible areas. Remote sensing offers the possibility of observing precipitation in real or near real time over relatively large areas and of complementing the conventional precipitation measurements. The remote sensing methods studied and used for rainfall monitoring are closely connected with the different types of precipitation.

One of the approaches of measurement of precipitation is using microwave radars. Radars can make rainfall measurements over relatively large areas and space resolutions. The radar-based measurements need frequent calibration adjustments. However, with the advent of satellites, a unique opportunity has opened up to make measurements from space covering large areas on a repetitive basis. The satellites carry typical payloads operating in visible, infrared and microwave spectral region. The satellite-based measurement is used to study and classify cloud systems and thereby estimate the potential precipitation.

7.0 Waterlogging

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, multispectral and multi temporal remote sensing data are very useful. The satellite data thus provide a quick and more reliable delineation of the water-logged areas and standing water.

The spatial distribution of soil affected by 'positional waterlogging'(i.e., that due to its location in the landscape) can be modelled 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 phenomena 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 which are susceptible to waterlogging.

One of the common practice in command areas for observing the water-logged areas 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 is also collected for the quality of water. The information thus collected is used to draw hydrographs and depth of water table to prepare the maps subsequently. So preparation of these maps can help a lot in the identification of waterlogged zones in a command area. Using field data which is available in the form of point data, ground water depth distribution map 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, particularly texture.

8.0 Snow Cover Studies

Measurements of snow cover in the mountainous basins are very difficult. Conventional methods have limitations in the monitoring of snow covered area in the Himalayan basins because of inaccessibility. Because of the difficulty of making field measurements in snow covered mountainous regions, remote sensing is perhaps the only means of measuring snow cover extent and properties. Fresh snow has a very high reflectivity in the visible wavelengths, however, it decreases as the snow ages. The reflectivity of snow is dependent on many snow characteristics like 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. In addition, the solar elevation and azimuth also influences the spectral reflectance to a large extent (Hall and Martinec, 1985).

Since, very little information on snow is collected regularly in the Himalayas, remote sensing remains the only practical way of obtaining some relevant information of the snow cover in the large number of basins in the Himalayas. At present the visible, near IR and thermal IR data from various satellite (Landsat, IRS, NOAA) are being used operationally for mapping the areal extent of snow cover in the Himalayan basins. Visible and near infrared wavelengths, because they do not penetrate far into the snowpack, mainly provide information about the surface of the snowpack. Chang et al. (1976) showed that microwave wavelengths can penetrate the snowpack. 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.

9.0 Reservoir Sedimentation

Most common 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 insitu or laboratory work.

With the introduction of remote sensing techniques in the recent past, it has become very 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 every 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 very different from that obtained with surface data collection and sampling.

10.0 Ground Water Assessment

Monitoring of ground water can be done by identification of phreatophytic vegetation, wider sandy channels, sinkholes and faults. Remote sensing system is quite helpful in ground water exploration as the remotely sensed data provide a large area synoptic view with high observational density. Using geomorphological features, as seen from the space as guide, areas with high, medium, and low potential of finding underground aquifers capable of being tapped, have been delineated in many drought prone states of India. The experience indicates that the percentage success for locating ground water using satellite imageries increased to almost 90% as against 40-50% success obtained using ground measurements alone.

11.0 Soil Moisture Assessment

Remotely sensed data have great potential for providing areal estimates of soil moisture rather than point measurements. Quantitative assessment of soil moisture regime is essential for water balance models, irrigation scheduling, crop management, surface and subsurface flow predictions. Remote sensing of soil moisture can be accomplished to some degree by all regions of the electromagnetic spectrum. The use and application of remotely sensed data for soil moisture depends upon the measurement of the electromagnetic energy that is reflected or emitted from the surface. Thus, either direct observations of the soil by remote sensors or indirect estimates using plant condition appear to be useful in soil moisture observations. Microwave remote sensing can directly measure the dielectric properties of the earth surface which in turn is strongly dependent on the moisture content. The physical relationship between moisture, dielectric properties and microwave response together with the ability of microwave sensors to penetrate clouds make them a useful all weather sensor. Estimation of soil moisture using remote sensors is still in research phase and is yet to be adopted for practical applications.

12.0 Watershed Management

Of the various attributes of watershed management, drainage network, soils, land use and soil erosion status are amenable to mapping and assessment by remote sensing technique. The priortisation of watershed helps in taking up soil conservation measures on a priority basis. Erosion Index (EI) based on actual and potential sediment yield estimates is also used for priortisation of watersheds.

13.0 Drought Studies

Space technology has made substantial contributions in every aspect of drought management such as preparedness, prevention and relief. While satellite communication have significant potential for real time dissemination of information and early warning, earth observations satellites enable continuous monitoring of atmospheric as well as surface parameters attributing to these phenomena. Thus considerable advances in operational use of space technology towards management and mitigation of droughts offer viable technological solutions to these problems.

India is one of the very few countries in the world using space technology for real time monitoring of agricultural drought condition. A unique feature of the Indian effort is spatial monitoring of drought conditions at the level of sub-district units such as *Thasils*, *blocks* and *mandals*. The National Agricultural Drought Assessment and Monitoring System (NADAMS) has been issuing periodical biweekly drought bulletins (1989-91) and monthly crop and seasonal condition reports (since 1992 onwards) in eleven agriculturally important and drought vulnerable states. Based on the analysis of nearly 10 years of database, quantitative relationship are being established between vegetation index parameters and the yield of major crops in the districts. Significant improvement is made in reducing turn around time of reporting period to two days by way of telegram/fax and 10 days for total reports. The NADAMS, during 9th five year plan will see significant improvement by way of more detailed drought monitoring for the entire country at different administrative levels using high resolution satellites like Indian Remote Sensing Satellite (IRS) of IRS 1A, IRS 1B, IRS 1D and IRS P3 in addition to NOAA satellite. By the end of ninth five-year plan, the program will be fully operationalised at user departments.

14.0 Urban Hydrology

There has been phenomenal growth of urban population as compared to rural population. As per census of 1991 urban population is 26% of rural population as against only 12% population at the time of Independence. This requires strengthening managerial capabilities, creating information base, formulation of services projects, presenting developmental needs, project management, monitoring and evaluation. Goal of all urban local bodies is to manage this growth and ensure proper environment.

Information forms basis of urban development planning. For this purpose, presently no up to date cadastral maps are available for cities in India. Other information needed is urban catchment, soil, land use, groundwater, topography. This information can be obtained from remotely sensed data. Existing cadastral maps can also be updated using remotely sensed data e.g. areal photographs.

The runoff curve number method of Soil Conservation Services (SCS), United Stated Department of Agriculture (USDA) is developed to estimate storm runoff volume for small agricultural watersheds and urban catchments (later modification). An urban catchment can be classified based on curve numbers. The land use, land cover and soil data could be deciphered using remote sensing technique and can be used in this method.

In planning process, many scenarios are needed to be analysed at all levels to select cost effective and most appropriate option. The information base may be continuously updated as any project and developmental activities progresses. Further, land use and land cover map prepared periodically using remotely sensed data can be useful in delineating groundwater recharge areas and natural drainage in an urban area which the town planner could utilise while planning the growth and development of an urban area.

15.0 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.

The Decision Support System (DSS) can be designed as an interactive, flexible and adaptable Computer Based Information System (CBIS), especially developed for supporting the solution of a management problem for decision making. It utilizes data, provides easy interface and allows for decision makers own insights for illustrating the objectives and information characteristics associated with the various levels of decision making. DSS provides a framework for incorporating analytical modeling capabilities with database to improve decision making process. Currently available DSS provide primarily for well-structured problems. These are also being used for decision making in water resources planning and management.

16.0 Conclusions and Future Needs

GIS, in combination with remote sensing technologies, is being successfully used in water resources studies. 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. 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.