REMOTE SENSING AND GIS APPLICATION IN RAINFALL-RUNOFF MODELLING

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1.0 GENERAL

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

2.0 DATA NEEDS

Data requirements vary with the geographical area, the type of model and the output requirements. The use of hydrological models for large watersheds and the shortage of good ground based data sources have hydrologists to make increasing use of remotely sensed data. The use of aircraft is an early and continuing example of remote data collection. As the scale of hydrological models increases to provide interaction with general circulation models and regional climate models, hydrologists must turn to the world-wide coverage provided by satellites. Precipitation is undoubtedly the most important input data for hydrological models and yet, at the moment, it can be estimated from satellite data only in special circumstances with limited accuracy. The techniques available for this purpose are cloud indexing, thresholding and life-history methods using visible and infrared data from NOAA and Meteosat/GOES satellites and using regression algorithms with passive microwave data from the Nimbus, DMSP and MOS-1 satellites. The most promising new technology is the series of recent active microwave satellites such as ERS-l, JERS-l and the forthcoming RADARSAT, which will allow hydrologists to use similar Z-R relationships as presently used with ground-based radar. In cold regions, the areal extent of snow cover is measured relatively easily at visible and infrared frequencies. Areal extent may be measured to within 20-30m using IRS, Landsat TM or SPOT images although this is at restricted return periods and in cloud-free conditions only. Hydrological processes such as interception, infiltration and runoff depend upon distributed catchment characteristics such as elevation, slope, aspect, vegetation cover and soil type. Land cover is a useful surrogate for many of these characteristics and can be accurately estimated by classification of data from optical sensors. Thus data from IRS, Landsat MSS and NOAA AVHRR are commonly used for watershed land cover measurements. Canopy interception forms an important component of total evapotranspiration from a watershed. The variation of leaf area index through the year for various species of vegetation can be modelled by computing vegetation indices from optical and near infrared frequencies; NOAA AVHRR data are commonly used. Evaporation has traditionally been one of the most difficult hydrological processes to estimate since direct measurements present many problems. Techniques are now becoming available to use satellite data to provide areal estimates of skin temperature, cloud cover/sunshine duration and surface albedo and to compute evapotranspiration from different land covers. In any hydrological model it is important to keep track of the temporal and spatial variation in soil moisture. Both passive and active microwave data have been used for this purpose.

3.0 USE OF REMOTELY SENSED DATA

The satellite capability to provide real time information makes it possible to have meaningful repetitive surveys, which can show the changes have taken place in a particular period in a catchment. Remote sensing technology for providing hydrological and morphological information such as physical characteristics, watershed boundaries and land use, catchment variables, soil moisture and snow cover have been recognised from a long time. In recent time the availability of remote sensing data, particularly satellite imagery in form of electromagnetic data from various spectral bands have a major effect on hydrological modeling. After manipulating, such information can be used as input for hydrological models. In recent years, satellite remote sensing and Geographical Information System (GIS) have emerged as powerful tools for collecting the requisite information on land use and land cover of large areas (Shih, 1988). Advantage of the information acquired by satellite remote sensing is of synoptic coverage, receptivity and spectral characteristics and especially in the easiness to compare the data before and after monsoons. Further, the information on land use/ land cover and hydrologic soil type can be integrated in a GIS environment for a quick and accurate estimation of runoff curve numbers.

4.0 GIS AND HYDROLOGIC MODELLING

GIS provides representations of the spatial features of the Earth, while hydrologic modeling is concerned with the now of water and its constituents over the land surface and in the subsurface environment. There is obviously a close connection between the two subjects. Hydrologic modeling has been successful in dealing with time variation, and models with hundreds or even thousands of time steps are common, but spatial disaggregation of the study area has been relatively simple. In many cases, hydrologic models assume uniform spatial properties or allow for small numbers of spatial subunits within which properties are uniform. GIS offers the potential to increase the degree of definition of spatial subunits, in number and in descriptive detail, and GIS-hydrologic model linkage also offers the potential to address regional or continental-scale processes whose hydrology has not been modeled previously to any significant extent.

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 modeling 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.

(1) The lowest level of integration consists of using GIS as an aid in developing the input data file for the model. A user then takes the preliminary files and modifies them to

produce a complete input file in the format required by the model. A similar procedure in the opposite direction can be applied to the outputs of the model in order to present and store them in GIS. This approach enables one to use an existing GIS and an existing model without modification to either but requires the most of user's effort.

(2) The next level of integration is to use an interfacing program specifically written to communicate between the GIS and the model. The interface program may serve as a control program issuing commands to the GIS and the model. Output from the GIS is converted into the proper input format for the model and then read by the model. Output from the model may likewise be converted to a GIS format and then displayed by the GIS. All these operations are carried out under the control of the interface program.

(3) A third level of integration occurs when the interface program is incorporated into the model. This requires modification to the input/output routines of existing models or developing special input/output routines for new models. Some programming may also have to be done within the GIS to alter its input/output structure to make it more compatible with that of the model. If one is making extensive changes to a model or developing a new model, this level of integration would be appropriate.

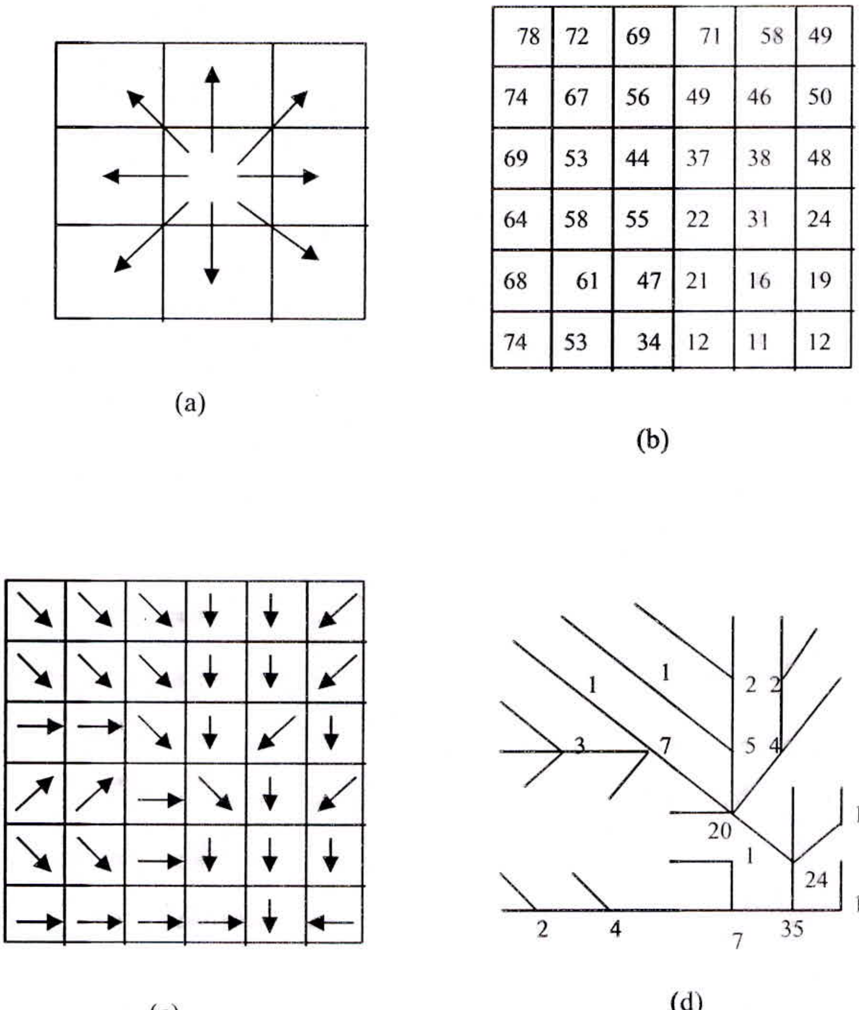
(4) The highest level of integration occurs when the model and GIS are essentially a single, integrated unit. One way of achieving this is by programming the model using the programming language appropriate to the GIS being employed. This makes GIS a master module, which controls the model runs.

In hydrologic analysis a GIS can play an important role due to its capabilities to describe the topography of a region. In the modern computer age the techniques used in the description of topography are called digital elevation models (DEM's). Some spatial information is not directly described by elevation, and can be described as topologic data. Topologic data define how the various pieces of the region are connected. Topology can be described as the spatial distribution of terrain attributes. DEM and GIS representations of topologic data are part of the general grouping of digital terrain models (DTM's). An example of hydrologic topology is the collection of lines describing a stream network. Another is the collection of points delineating subregions of a watershed. Both forms of information are related to topography, but may be defined in a topological sense based on the topographic portion of the GIS data base.

While topographic data fit within the general classification of topologic data, there are significant hydrological attributes not related to land surface elevation. The more obvious of these are catchment areas, flow lengths, land slope, surface roughness, soil types, and land cover. These attributes help to describe the ability of a region to store and transmit water. Some topologic attributes are tied to the concept of a watershed unit. The most basic of these is the description of the watershed boundary. Given a drainage point, the topography alone can be used to define those areas that should drain to the point. Average slope and drainage path networks are related, topographically derived, topologic attributes. These attributes are useful in determining watershed attributes such as time of concentration, flow potential energies, and flow attenuation. The sorting and manipulation capabilities of a GIS are well suited to extracting such attributes.

GRID-BASED FLOW PATTERN

Most of the raster based GIS systems contain routines, which determine the flow direction over land surface terrain using pour point model. Water on grid cell is permitted to flow to one of its eight neighboring cells. By taking a grid of terrain elevations, determine the slope of the line joining each cell with each of its neighboring cells, a grid of flow directions is created with one direction for each cell which represents the direction of steepest descent among the eight permitted choices. The concept of grid based flow pattern is represented in Figs. 1(a), 1(b), 1(c) and 1(d). The grid in figure 1(c) is shown as a set of arrows but infect is stored in GIS as a grid of numbers where each flow direction has a unique identifying number. By assigning water flow to one of its eight neighboring cells, equivalent one dimensional flow network is constructed by connecting the cell centers in the direction of flow as shown in Fig. 1(d). There is thus a duality between the grid and equivalent flow network and one might call the network so created a hybrid grid-network.



78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

Fig. 1 Watershed terrain analysis using grid GIS method: (a) the eight direction pour point model; (b) a grid of terrain elevations; (c) the corresponding grid of flow directions; (d) the equivalent network showing flow accumulation.

RAINFALL-RUNOFF MODELLING USING REMOTE SENSING AND GIS

SCS Curve Number Method

The SCS model computes direct surface runoff through an empirical relation that requires the rainfall and a watershed coefficient namely runoff curve number (CN) as input. The curve number is a function of some of the major runoff producing properties of a basin namely, the hydrologic soil type, land use and treatment, ground surface condition and antecedent moisture condition. Of these, the determination of land use and land cover is one of the most important tasks for estimation of runoff curve number. The prime variable in the basin wide runoff curve number estimation is land use changes with the time.

The runoff curve number method is a procedure for hydrologic abstraction developed by the USDA Soil Conservation Service. In this method, runoff depth (i.e. effective rainfall) is a function of total rainfall depth and an abstraction parameter referred to as runoff curve number or simply curve number which is usually represented by CN. The curve number varies in the range 1 to 100, being a function of the following runoff producing catchment properties: (1) hydrologic soil type, (2) land use and treatment, (3) ground surface condition, and (4) antecedent moisture condition.
The method is based on an assumption of proportionality of the following form:

$$\frac{P - I_a - Q}{S} = \frac{Q}{P - I_a} \qquad (29)$$

where; P = total storm rainfall, Q = actual direct runoff, S = potential maximum retention, and I_a = initial abstraction. P, Q and S are expressed in the same units e.g. cm or inches. This assumption underscores the conceptual basis of the runoff curve number method.

Solving for Q from Eq. (1) leads to the following.

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad (30)$$

which is physically subject to the restriction that $P \geq I_a$ (i.e. the potential runoff minus the initial abstraction cannot be negative). To simplify Eq. (30), initial abstraction is related to potential maximum retention. The relationship between initial abstraction and potential maximum retention for Indian conditions has been developed.

For Black Soil Region (Antecedent Moisture Condition I) and For All Other Regions:

$$I_a = 0.3S \quad (31)$$

Therefore Eq. (30) reduces to

$$Q = \frac{(P - 0.3S)^2}{P + 0.7S}, \qquad P \geq 0.3S \quad (32)$$

For Black Soil Region (Antecedent Moisture Condition II & III):

$$I_a = 0.1S \quad (33)$$

Therefore Eq. (30) reduces to

$$Q = \frac{(P - 0.1S)^2}{P + 0.9S}, \qquad P \geq 0.1S \quad (34)$$

Eq. (34) is used with the assumption that the cracks which are typical of black soil when dry are filled.

Since potential maximum retention varies widely, it is expressed in terms of a runoff curve number, an integer varying in the range 1 to 100, in the following form.

$$S = \frac{2540}{CN} - 25.4 \quad (35)$$

in which CN is the runoff curve number (dimensionless) and S is in cm. Hence, the values of P and Q in Eqns. (32) and (34) are also to be expressed in cms. The runoff curve number is a function of hydrologic soil group, land use and treatment, hydrologic surface condition and antecedent moisture condition.

5.0 CONCLUDING REMARKS

The use of remote sensing technique for determination of land use/cover not only saves time but is less expensive as compared to conventional methods like ground surveys. Further, the satellite based remote sensing has advantages like large area coverage, synoptic view and capability to provide information over all accessible and inaccessible regions. Land use and hydrologic soil information of the basin serve as the basic input to the curve number technique. Geomorphological characteristics, which are quite commonly used in geomorphological based instantaneous unit hydrograph, can be evaluated using a GIS package. Manual estimation of the geomorphological parameters is a tedious and cumbersome process and often discourages the field engineers from developing the regional methodologies for solving various hydrological problems of the ungauged basins or in limited data situations. At times, it also leads to erroneous estimates. On the other hand, modern techniques like the GIS serve as an efficient approach for storage, processing and retrieval of large amount of database. Spatial modelling and tabular databases of GIS constitute a powerful tool and enable a kind of analysis which was not possible until recently. Also, the database created and stored in GIS system may be updated as and when required.